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DEVELOPMENT OF STOICHIOMETRIC DIESEL CONCEPT: PHASE II

DAAE07-89-C-R014

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This report is an account of work performed on an SBIR Phase II work effect. The report details the results of a research program to design, construct and test a diesel engine which operates at stoichiometric air-fuel ratio. The program has shown that it is possible to achieve acceptable combustion with non-visible smoke emission at stoichiometric air/fuel ratio using a single cylinder Caterpillar 1Y73 laboratory engine. Based upon engine test results, computer analysis shows that the current U.S. Army 600 horsepower diesel engine used in the Bradley Fighting Vehicle can be increased to 950 horsepower with no increase in air flow or peak cylinder pressures by using the stoichiometric concept and incorporating turbocompounding to recover the additional exhaust energy.

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1.0. INTRODUCTION

This final technical report prepared by Adiabatics, Inc. for the U.S. Army Tank-Automotive Command (TACOM) describes the technical findings and conclusions reached under Contract No. DAAE07-89-C-R014 "Development of Stoichiometric Diesel Concept." This contract was for a Phase II Small Business Innovative Research (SBIR) program to experimentally determine the performance of a unique diesel engine which was designed to operate at a stoichiometric air/fuel ratio.

As an aid to understanding the stoichiometric concept, all engines can be thought of as chemical processors utilizing two ingredients in a reaction to produce power with the by-products of a heated exhaust stream (which contains residuals from the chemical reaction) and also waste heat through the structure. The two input ingredients are air and fuel. Different engine types operate with different proportions of these ingredients. When the proportions of air and fuel are chemically correct to allow for complete reaction of the fuel and air so that there is neither fuel or oxygen in the exhaust stream, the mixture is defined as "Stoichiometric." Gas turbines and normal diesel engines operate with large amounts of excess air and are referred to as lean burn engines. The normal gasoline engine operates at a stoichiometric mixture.

The advantage to the military of using stoichiometric engines as opposed to lean burn engines is a large reduction in the size and weight of the total powerplant. This reduction is the result of reduced airflow requirements (smaller ducts, smaller turbocharger, smaller charge air cooler, smaller radiator, smaller air cleaner and smaller exhaust silencer) as well as reduced engine size due to lower airflow. The resulting lower compression and peak cycle pressures mean that a given engine size can produce more power.

2.0. OBJECTIVES

The objective of this Phase II program was to demonstrate proof of concept (by laboratory engine tests) that the power output of a stoichiometric diesel can be increased by 45 percent without increasing peak cylinder pressure and without any appreciable loss of fuel economy while retaining acceptable smoke levels.

A primary objective was to determine by analysis which of the two engine concepts, the Thermal Ignition Combustion System (TICS) or the High Pressure Direct Injection (HPDI), possesses the greater potential for the stoichiometric diesel engine and then use the best approach for the engine tests.

3.0. CONCLUSIONS

The first conclusion reached during this program was that existing cycle simulations predict that both the TICS and HPDI have the potential to achieve stoichiometric diesel combustion with resulting large increases in power output and minimal effect on fuel consumption and smoke.

The second conclusion based on the single cylinder laboratory engine test results was that a successful multicylinder stoichiometric diesel engine can be developed. Table 3.0-1 lists the characteristics of the stoichiometric diesel compared to a conventional military diesel engine. Turbocompound versions of both engines are also compared. The base engine used for the multicylinder comparison is the military version of the Cummins V903 engine which is rated at 600 horsepower. By converting the engine to stoichiometric operation without changing the compression ratio or increasing speed or peak pressure, the power output can be increased to 870 horsepower (45 percent increase). The table also shows that despite a 10% drop in combustion efficiency (i.e. 15 ISFC), the resulting engine with a 45 percent increase in power density has a fuel consumption penalty of only five percent at rated conditions. In order to take full advantage of the stoichiometric engine concept, it is necessary to incorporate turbocompounding. Comparing the turbocompound version of the V-903 to the stoichiometric turbocompound version the power is increased from 630 horsepower to 959 horsepower (52 percent increase) with no increase in fuel consumption. For this 52 percent increase in power density (of the basic engine), the total airflow requirements are reduced from 8680 lbs per hour to 5724 lbs per hour (34 percent reduction). Additional improvements in power density will result from reductions in the size and weight of the air handling system (intake and exhaust ducting, air cleaner, intercooler, turbocharger and muffler) and from reductions in the size and weight of the engine cooling system.

4.0. RECOMMENDATIONS

Based upon the results of this program, it is recommended that the U.S. Army investigate the implications of using the stoichiometric diesel engine in a high performance vehicular application such as a heavy tank. Following this analytical study, the U.S. Army should encourage the further development of the engine by funding the continued development of enabling technologies for a multicylinder stoichiometric demonstration engine. It is recognized that continued development of the stoichiometric diesel, including meaningful demonstrations, will not be possible due to the high risk of premature component failures (which limited the testing during this Phase II SBIR program). The enabling technologies include:

- Fuel injection systems with cooled nozzles for 300+ psi BMEP
- High temperature turbochargers (1800^{o}F turbine inlet)

Table 3.0-1 Stoichiometric Engine Comparison

STOICHIOMETRIC ENGINE COMPARISON

CHARACTERISTIC	TURBOCHARGED STANDARD	TURBOCHARGED STOICH.	TURBOCOMPOUND STANDARD	TURBOCOMPOUND STOICH.
AIR/FUEL RATIO	28	18	28	18
RATED BMEP (psi)	202	293	213	315
RATED IMEP (psi)	237	328	248	350
OUTPUT (BHP)	600	870	630	935.4
ISFC (lbs./IHP/hr.)	0.298	0.328	0.286	0.307
BSFC (lbs./HP/hr.)	0.350	0.367	0.333	0.341
FUEL FLOW (lb/hr.)	210	319	210	319
AIR FLOW (lb/hr.)	5880	5747	5880	5730

THE FOLLOWING CHARACTERISTICS ARE CONSTANT

DISPLACEMENT (cubic inches)	903
PEAK CYLINDER PRESSURE (psi)	2,000
RATED SPEED (rpm)	2,600
NUMBER OF CYLINDERS	8
BORE (inches)	5.50
STROKE (inches)	4.75

- o High temperature precombustion chambers (1800^{O}F)
- o High temperature engine components (i.e. head, piston, liner)
- o Combustion system optimization

Following the technology enablement phase, a full scale demonstrator engine, such as a 950 horsepower stoichiometric Cummins V-903 engine, should be developed and demonstrated.

5.0. DISCUSSION

5.1. Background

An SBIR Phase I program (contract no. DAAE07-87-R057) was performed by Adiabatics, Inc. starting in July 1987 and ending in December 1987 [1]. The specific objectives of this contract were:

1. Design of thermal ignition combustion system (TICS) chamber and design of compatible adiabatic engine.
2. Development of analytical tools:
   a) Heat release model
   b) Combustion model
   c) Transient heat transfer.
3. Analysis by diesel cycle simulation:
   a) Develop combustion model for thermal ignition chamber and adiabatic engine
   b) Parametric analysis of important parameters
   c) Performance
   d) Engine characteristics
   e) Turbocharger requirements.
4. Techno-economic trade-off for an optimized TICS adiabatic engine for stoichiometric operation and design of same.

A parametric performance study was conducted using engine cycle simulations to compare the stoichiometric engine to existing powerplants. The four diesel engine concepts analyzed were:

1. conventional, turbocharged, water-cooled

2. turbocompound, low-heat-rejection

3. stoichiometric, turbocharged, low-heat-rejection

4. stoichiometric, turbocompound, low-heat-rejection

Three displacements of each of the four engine types were compared consisting of 5.5, 10.0 and 14.0 liters. In order to make the results comparable on an unbiased basis, the following conditions were held constant:

1. Peak cylinder pressure at rated speed and load

2. Timing of peak cylinder pressure

3. Mean piston speed

4. Compression ratio

5. Bore to stroke ratio

6. Stroke to connecting rod length ratio

7. Compressor and turbine efficiencies

The details of the simulations, the input data lists, and the numerical results are presented in the Phase I final report [2]. Graphical summaries of the results are shown as Figures 5.1-1 through 5.1-3. Figure 5.1-1 shows that the stoichiometric turbocharged engine should produce about 45 percent more shaft power than a conventional turbocharged diesel engine. The turbocompound version of the stoichiometric engine should produce 61 percent more power than the conventional turbocompound engine. Figure 5.1-2 shows that the fuel economy of the stoichiometric engine should be virtually the same as the standard diesel engine for both the turbocharged and turbocompound configurations. The conclusion from these two curves is that a considerable increase in shaft power, with no increase in specific fuel consumption, should result when an engine is converted to stoichiometric operation.

Since engines are normally compared on an installed basis in order to deliver a given power output, a better way to illustrate the advantage of using stoichiometric engines is shown as Figure 5.1-3. This figure shows power output versus engine installed weight. Examination of this figure reveals a weight saving of more than 40 percent.

The program identified two approaches for making a stoichiometric diesel engine. The first was to utilize a High Pressure Direct Injection system that uses very high injection pressures to provide the mixing

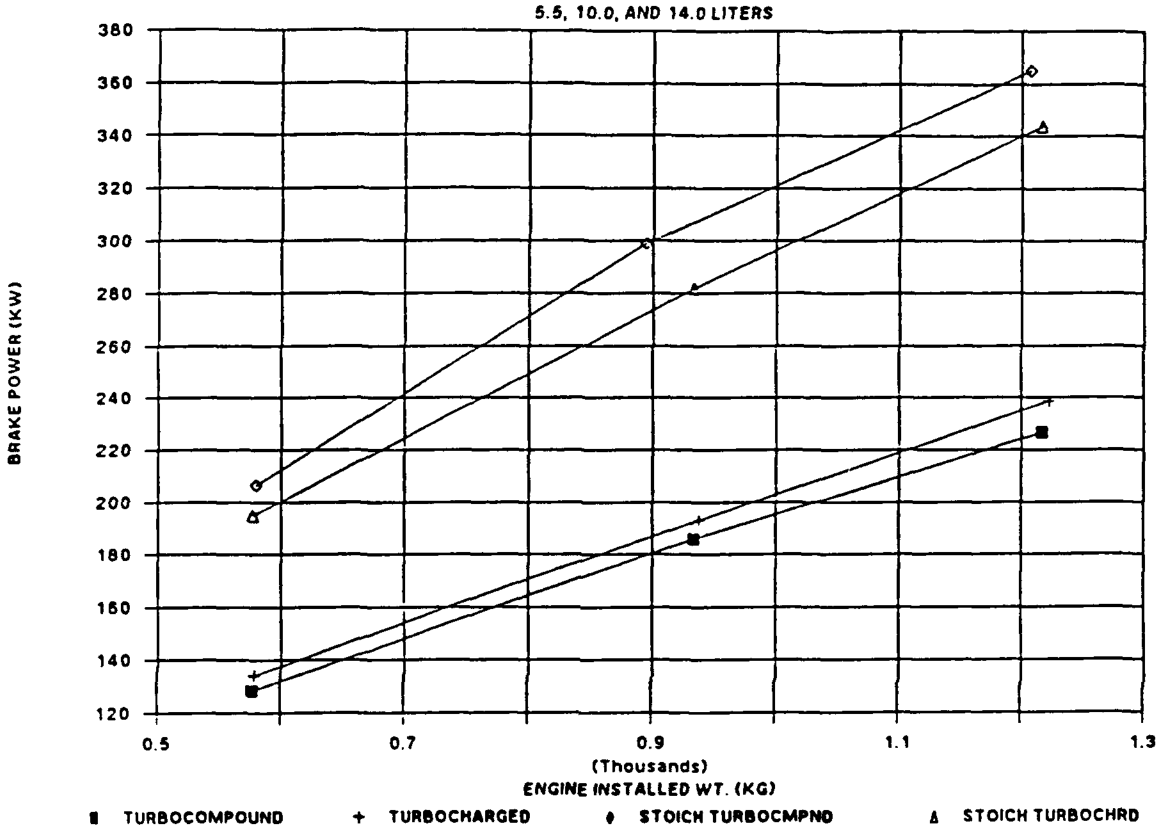

Figure 5.1-1 Brake Power vs. Engine Wt. (Metric)

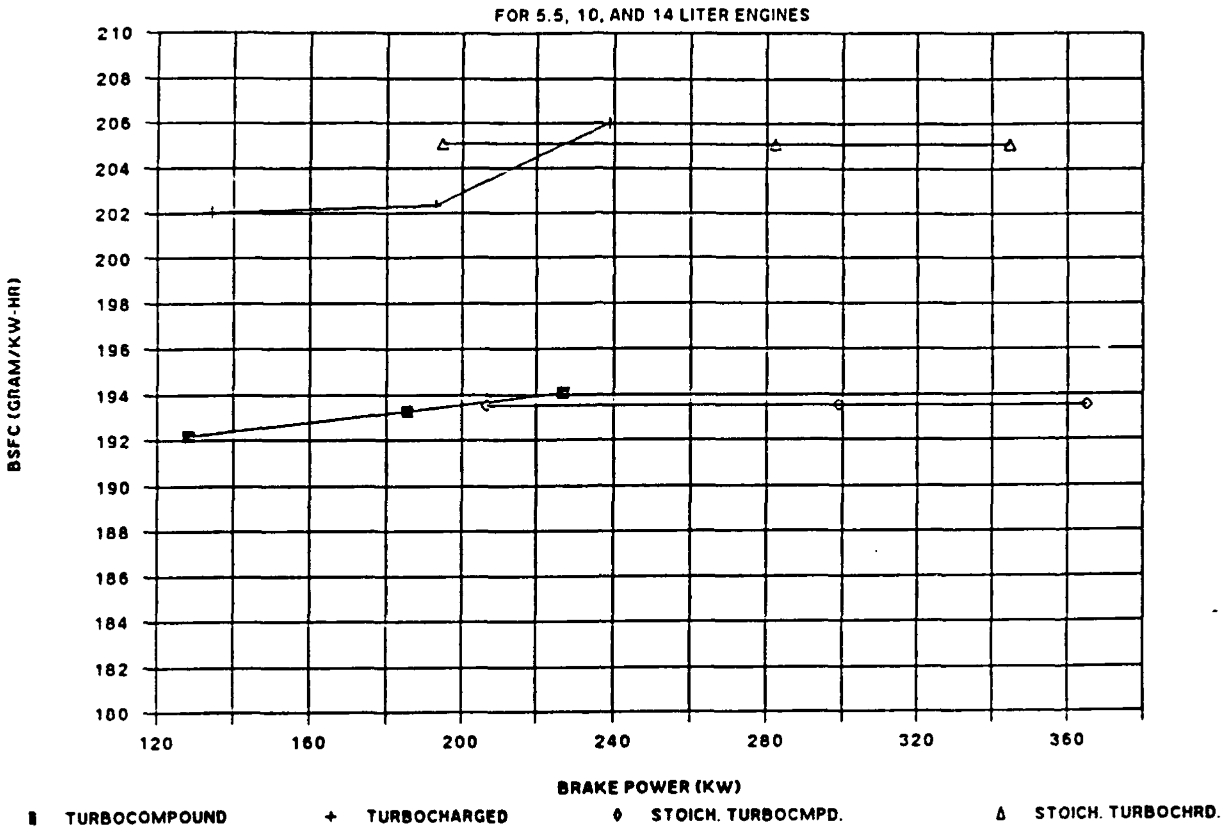

Figure 5.1-2 BSFC vs. Brake Power (Metric)

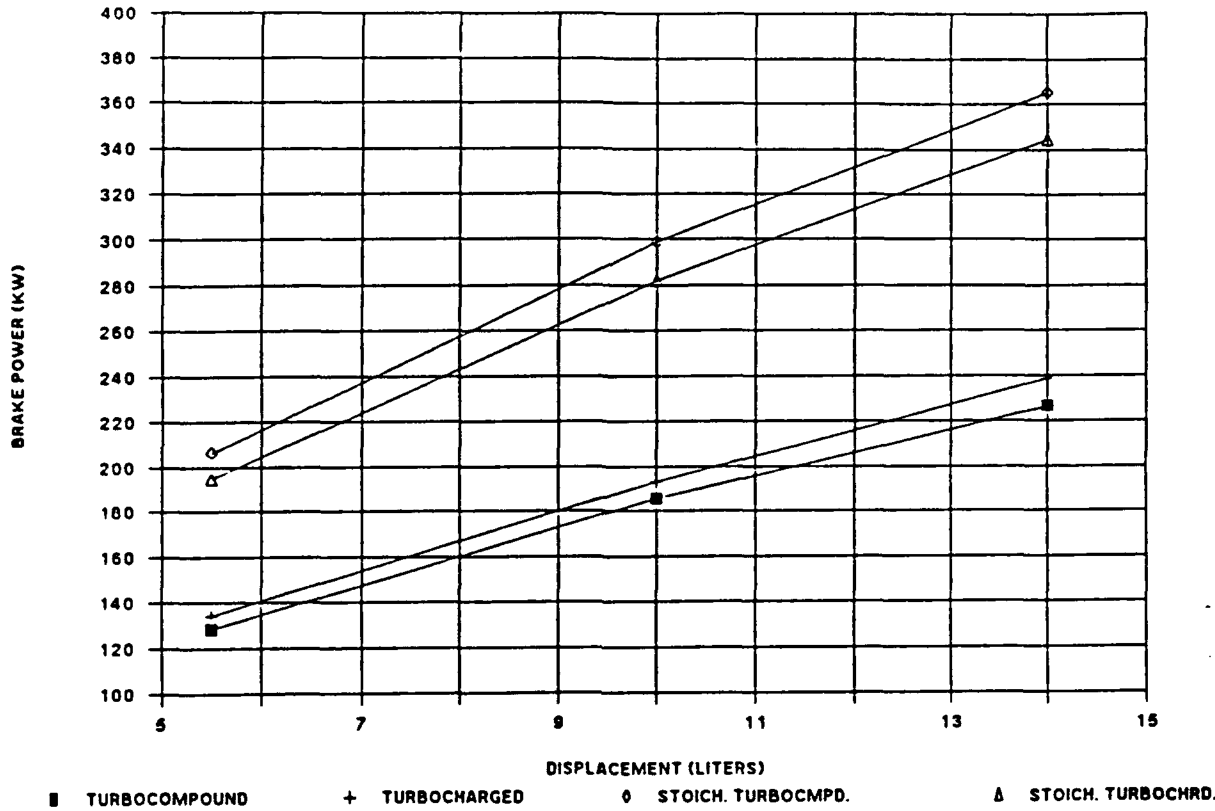

Figure 5.1-3 Brake Power vs. Displacement (Metric)

energy necessary to cleanly burn diesel fuel at stoichiometric air/fuel ratios. Previous test results utilizing this approach were shown. A second approach utilizing an uncooled engine with the Thermal Ignition Combustion System (TICS) [3] was used for all of the combustion modeling. The hypothesis which makes this approach attractive [4] is that you are able to utilize a hot walled precombustion chamber to eliminate ignition delay, then quickly burn the partial products of combustion from the prechamber (such as carbon monoxide and hydrogen) within the main chamber, provided the in-cylinder gas temperatures can be maintained above a critical threshold level (about 1,370 ^{o}C). The high velocity jet leaving the prechamber is used to promote mixing in the main chamber similar to the effect of high pressure injection.

5.2. Project Description

Pursuant to the contract requirements, a program was defined to meet specified highly detailed milestones. Figure 5.2-1 was the overall program schedule which shows nine tasks and a two year time schedule. The contract was signed and started on March 29, 1989. On March 19, 1991, a six month (no cost) time extension was granted to compensate for time lost due to a relocation of Adiabatics' facility in 1990. An important program guidance function was the inclusion of semiannual steering committee meetings held at TACOM. There were four formal steering committee meetings held on the following dates:

First	May 23, 1989
Second	April 11, 1990
Third	December 20, 1990
Fourth	July 15, 1991

5.3. Task I - Program Plan

This first task had three major objectives:

1. Identification and evaluation of alternatives and options

2. Selecting and locating a suitable test engine

3. Generating a Test Plan

Immediately following the start of the program on March 29, 1989, a study was started to select either the High Pressure Direction Injection (HPDI) or the Thermal Ignition Combustion System (TICS) approaches. An intensive literature search and simplified analyses were conducted to provide inputs to the selection procedure. On May 23, 1989, the first steering committee meeting was held at TACOM and it was concluded that there was insufficient information to select between the two concepts; therefore, it was recommended that both approaches be pursued through engine testing. This recommendation was not accepted by TACOM. It was suggested that further analysis consisting of cycle simulations of both the HPDI and TICS be conducted to enable a selection to be made.

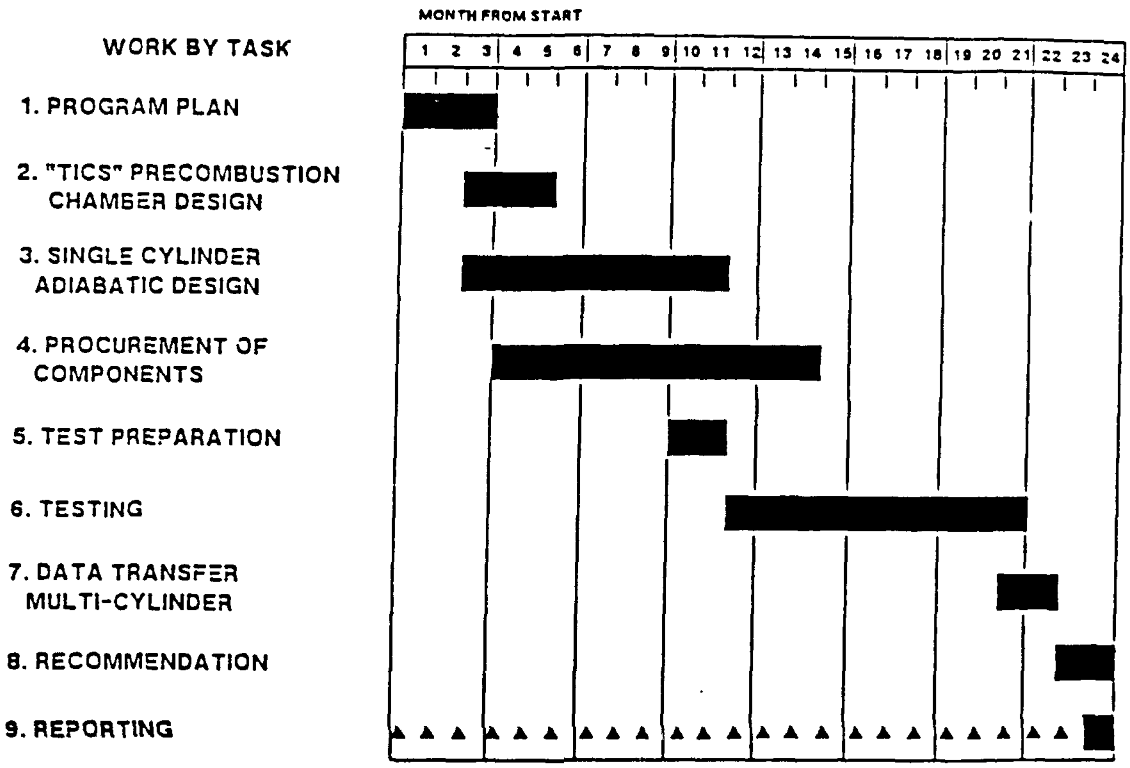

Figure 5.2-1 Time Phase Chart

Dr. Victor Wong, Manager of the Sloan Automotive Laboratory at the Massachusetts Institute of Technology, was subcontracted to prepare the models for both combustion concepts and assist in setting up and running the models at Adiabatics' facility. There were significant delays in obtaining and running these models with the net result being that the results were not available until April 1990. In addition to the modeling efforts, a short engine test series was conducted at Adiabatics using a single cylinder Caterpillar model 1Y73 engine to provide data for the TICS modeling effort. The results of the modeling were presented at the second steering committee meeting on April 11, 1990. The conclusions reached on the results of the modeling were that there were major errors and the results could not be used to compare the two approaches. Following a lengthy discussion of this and other data and reports, the conclusion was that TICS and HPDI should perform equally well. There was no clear technical reason to select one over the other. However, since the HPDI approach was being investigated by other researchers for TACOM, it was decided that the TICS approach would be pursued through engine testing.

During the first year of the program, work was conducted to select a suitable test engine. Since the selection of concept was not made, an engine was selected that would enable us to use either the HPDI or TICS approach. It was decided that a four stroke cycle, four valve per cylinder engine with adequate room for either a central high pressure injector or a central TICS precombustion chamber was preferred. Following a short search, a complete single cylinder engine and dynamometer, which was reported to be a Cummins NH Single Cylinder Engine, was located at MIT's Sloan Automotive Laboratory. MIT had recently obtained the engine from Sandia and was willing to lend it to Adiabatics at no cost. This engine was returned to MIT in supposedly good condition at the end of the program at Sardia. Three months later (September 1989) the engine was delivered to Adiabatics and was determined to be a Cummins V6-200 "Vim" series engine, which was a version of the predecessor to the V903. Following a short search, it was determined that it was virtually impossible to obtain adequate support hardware to enable us to use this engine; therefore, a decision was made to abandon it. An existing single cylinder Cummins NH carcass (consisting of a special block and crankshaft), which was the property of Adiabatics, was then selected and efforts began to prepare it as the test engine. At the second steering committee meeting it was decided that the Cummins NH engine should not be used as it is identified as a direct injection (DI) engine and that an existing indirect injection (IDI) engine should be located and used. A Caterpillar 1Y73 single cylinder IDI engine was located at Southwest Research Institute and was delivered to Adiabatics during May 1990.

Following the design of the stoichiometric hardware and the initial shakedown and baseline testing of the engine, a detailed Test Plan for stoichiometric testing was prepared and delivered February 1991. This Test Plan was extensively revised and resubmitted in May 1991. A copy of the revised Test Plan is included as Appendix A.

5.4. Task II - TICS Combustion Chamber Design

The TICS system design had four major objectives as follows:

1. Design for low "throat" loss

2. Design for low "heat" loss

3. Design for high "heat release" rate

4. Injection system design and modifications

The primary tool, which was utilized to design the combustion system, was the diesel cycle simulator as modified by Dr. Victor Wong. Figures 5.4-1 and 5.4-2 show the effects of TICS chamber volume and throat to body diameter ratio on efficiency. Based upon these plots, it was concluded that an extremely large volume TICS combustion chamber, which utilized virtually 100 percent of the clearance volume, with a throat diameter approximately 50 percent of the TICS chamber body diameter would be optimum. The Caterpillar 1Y73 engine has a 5-1/8 inch bore and 6-1/2 inch stroke for a displacement of 134.1 cubic inches. The standard engine has a total clearance volume of 8.65 cubic inches which results in a compression ratio of 16.5.

The TICS combustion chamber consists of a space separate from the cylinder volume which connects to the cylinder volume via a passage referred to as the throat. In order to accomplish the goal of thermally igniting the fuel, it is necessary to maintain the temperature of the TICS chamber inner walls at a high level and to inject the fuel directly into the TICS chamber. Attempts were made to design a TICS chamber that would replace the standard water-cooled Caterpillar 1Y73 precombustion chamber, which has a volume of only 28.8 percent of the total clearance volume with a larger uncooled precombustion chamber that uses at least 75 percent of the total clearance volume. These designs were not deemed to be practical and therefore attention was turned to placing the TICS chamber in the piston. A piston was designed using this approach that managed to place 91 percent of the clearance volume into the TICS combustion chamber. In order to minimize throat losses and to optimize the diameter of the throat, the piston was designed to have replaceable throat plates which could be fabricated with diameter ratios from 0 to 0.9. Conventional precombustion chamber type designs were also designed with several different volume ratios and throat diameter ratios.

Figure 5.4-3 is a sketch of the TICS combustion bowl designed to be placed into the piston crown and is referred to as Bowl #1. This first design incorporates 91 percent of the total clearance volume and has a throat to body diameter ratio of 0.9. This design was tested in Build II. Figure 5.4-4 is the same basic geometry except that the throat to body diameter is 0.5. This design was never tested. Figure 5.4-5 shows the three piece TICS precombustion chamber designs which have volume

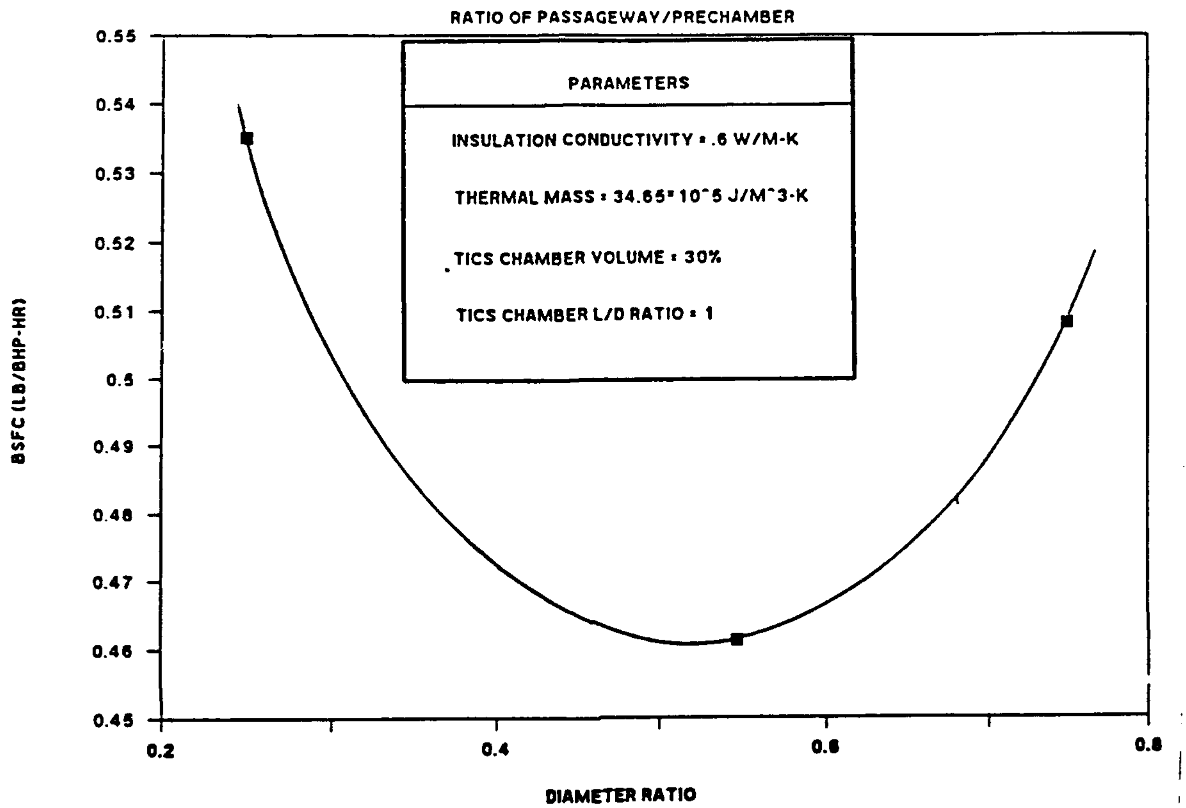

Figure 5.4-1 BSFC vs. Diameter Ratio

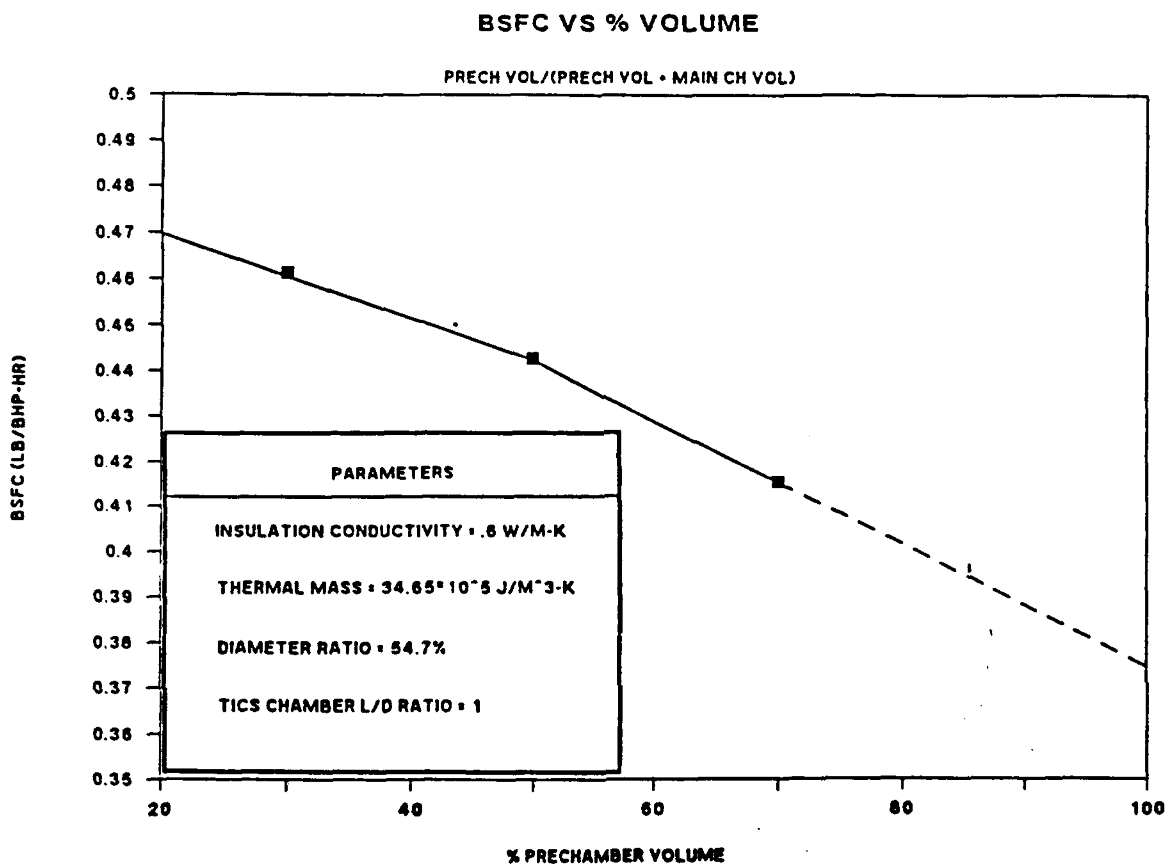

Figure 5.4-2 BSFC vs. % Volume

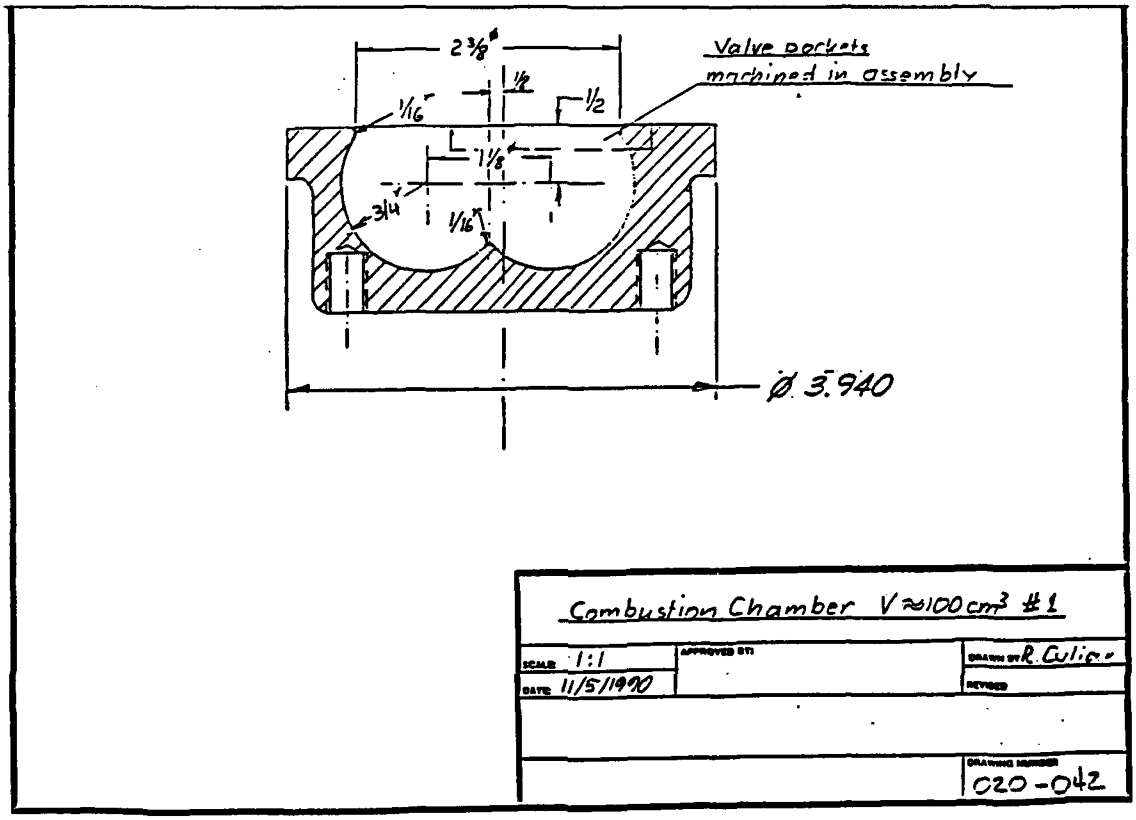

Figure 5.4-3 Combustion Chamber - (Bowl #1 - Hastelloy X)

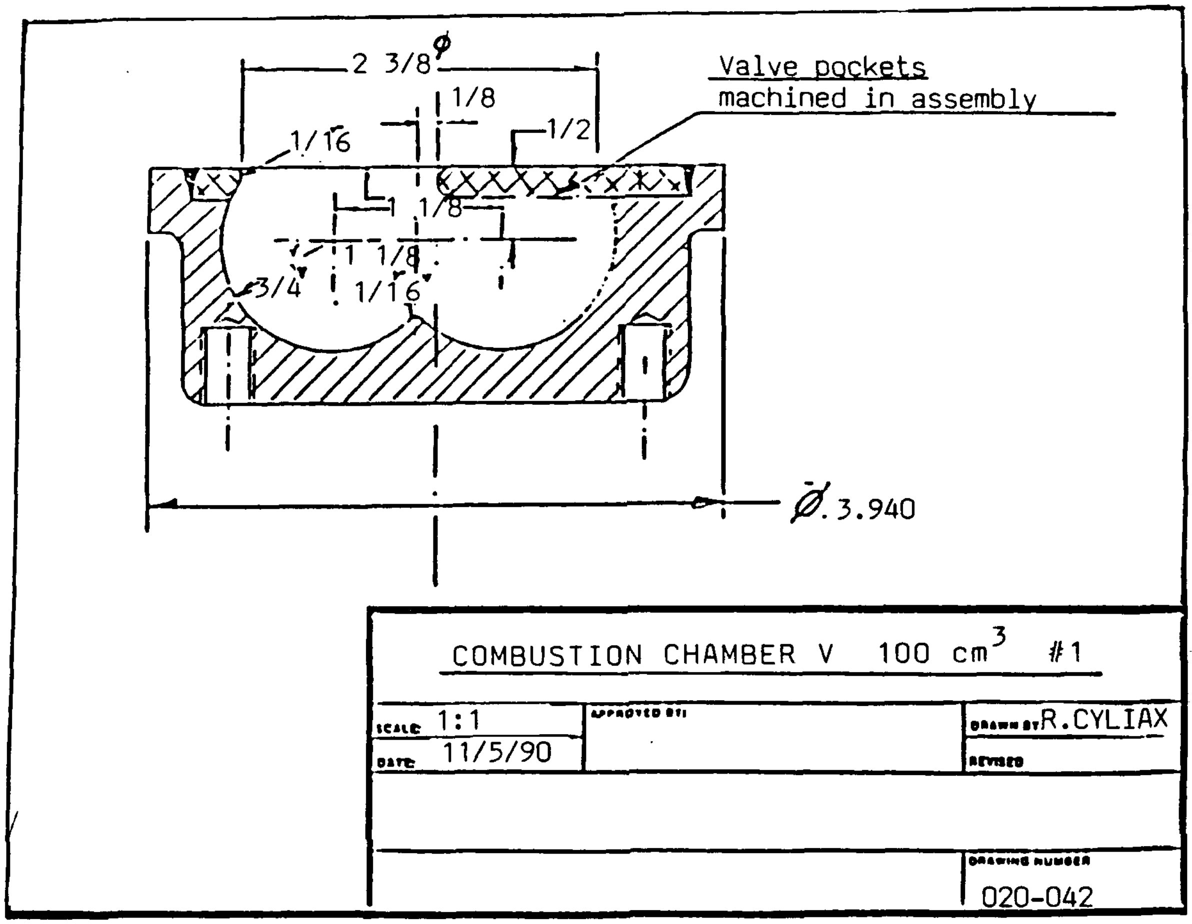

Figure 5.4-4. Combustion Chamber - (Bowl #3 - Hastelloy X with Narrow Throat)

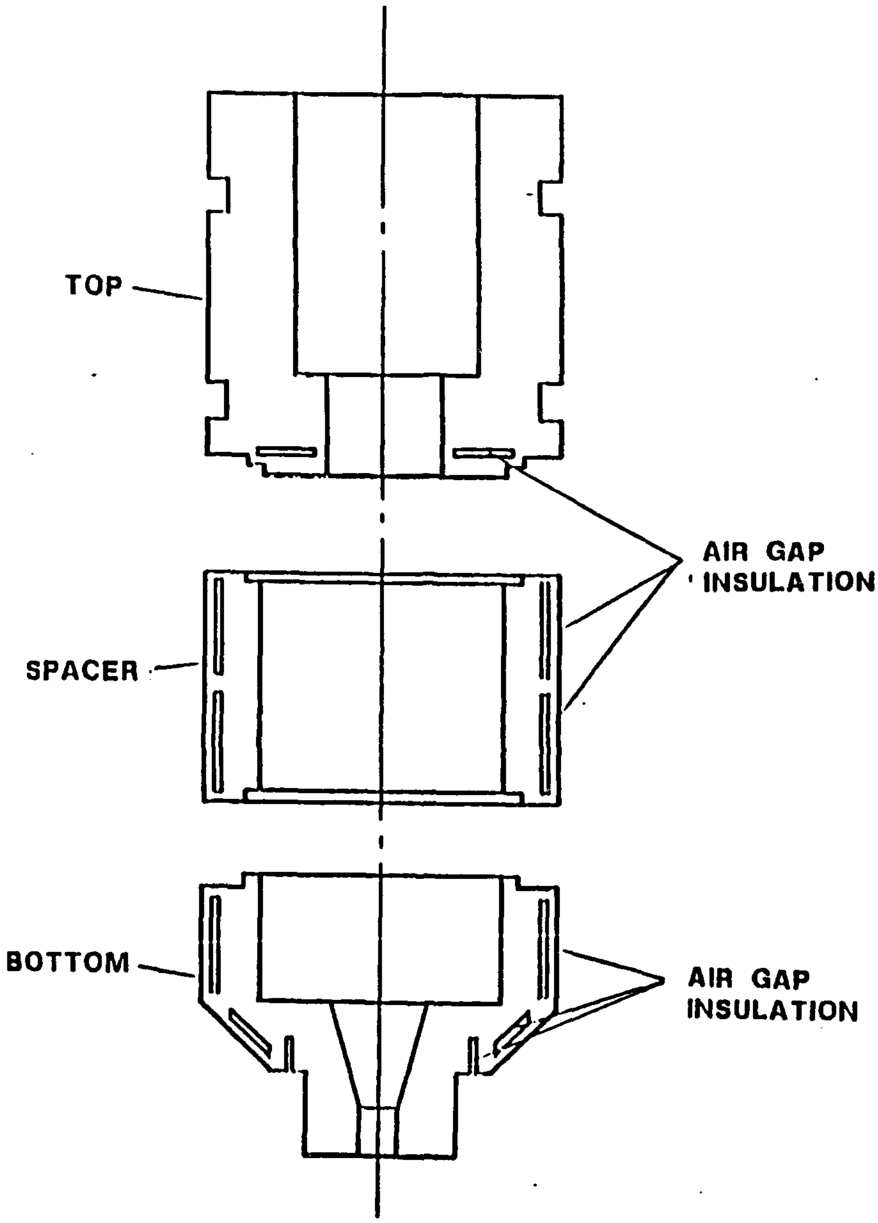

Figure 5.4-5 TICS Chamber with Spacer for Stock and 50% Volume Ratio

ratios of 24.6 (Build VI) or 40.4 (Build VII) depending upon whether the spacer is utilized. Table 5.4-1 is a summary of the four basic TICS chambers which were designed (and the build number in which they were later tested). The last configuration (Build VIII) uses the same TICS chamber as Build VII except that the clearance volume of the main chamber is reduced to increase the volume ratio to 49.4.

The last objective of this design task was to plan and execute the fuel injection system for the test engine. A variety of fuel system types were explored ranging from utilizing the existing Caterpillar single plunger pump and Caterpillar nozzle, to adapting a commercially available single plunger pump and water cooled nozzle to possibly purchasing a research type fuel system. In order to obtain the desired flexibility of operation including adjustable variable injection timing (variable without stopping the engine or reducing load) and still stay within budget, it was decided to use a jerk type fuel pump with a variable timing device and a conventional water-cooled nozzle. Figure 5.4-6 is a sketch showing the fuel injector and the adaptor which was designed to make it conform to the existing cylinder head precombustion chamber location.

5.5. Task III - Single Cylinder Adiabatic Design

The objective of this task was to design components for the engine to enable the engine to be run without cooling (adiabatic). The key components which were designed were:

1. Piston
2. Cylinder Liner
3. Cylinder Head
4. TICS Precombustion Chamber
5. Intake and Exhaust Ports

Two types of pistons were designed for this program. The first piston was designed for the TICS chamber in the piston concept as shown in Figure 5.5-1. The piston consists of three basic components. A standard aluminum Caterpillar 1Y73 piston was modified by cutting off the top, machining, and I.D. threading a large diameter cylindrical cavity into the upper part of the piston. A steel cup shaped component was then threaded into the aluminum piston to provide a sealed chamber in the top of the piston. The last step was to press the TICS chamber into the top of the well, on top of the piston, and secure it with bolts from the bottom. This design utilizes the captive and sealed air-gap between the TICS chamber and the cup shaped component to insulate the TICS chamber from the rest of the piston. Since the TICS chamber operates hotter than the rest of the piston and is made of a high hot strength material (Hastelloy X), it was necessary to design for high

Table 5.4-1. Design Parameters

BUILD	CR	VR (%)	TH. BORE (IN)	DIA. RATIO
II	19.2	91.1	2.375	.90
VI	14.2	24.6	.300	.20
VII	11.5	40.4	.300/.500	.18/.31
VIII	13.9	49.4	.2/.3/.5	.12/.18/.31

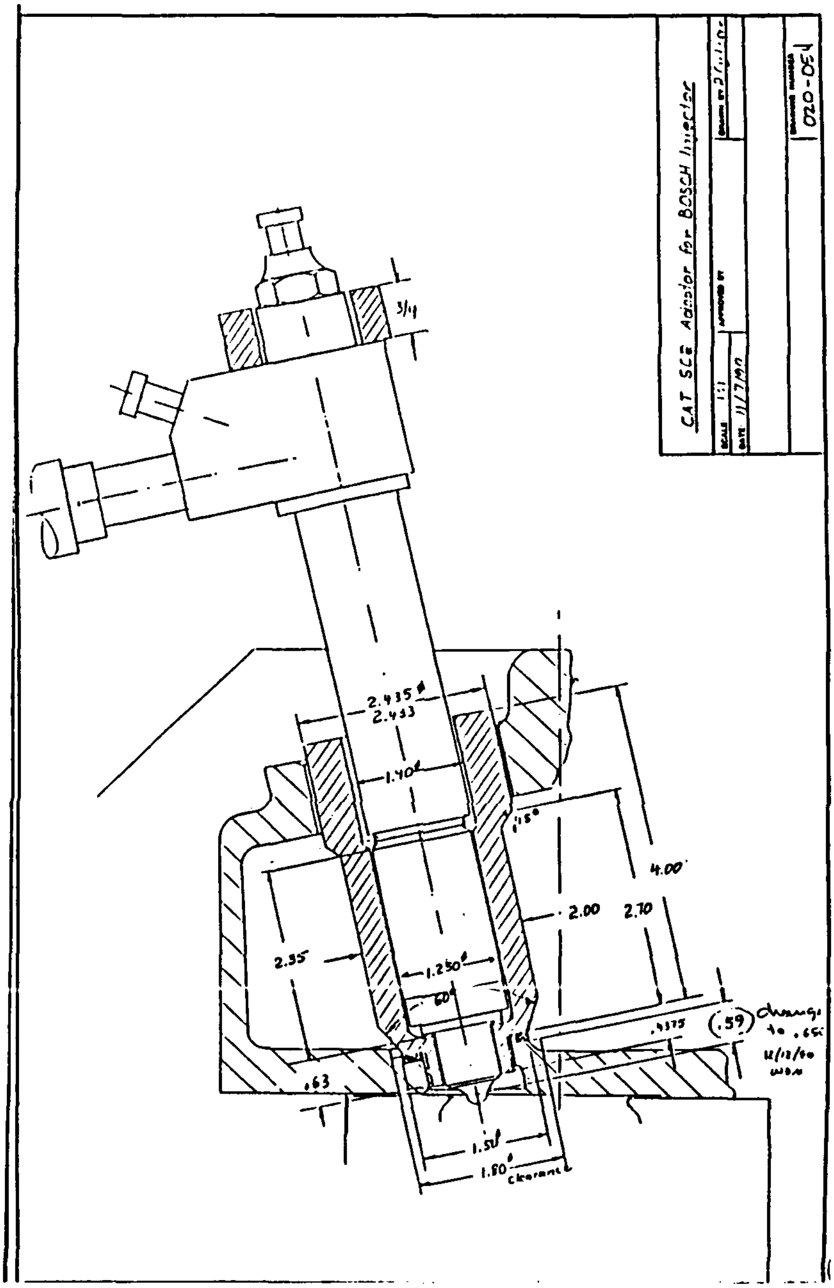

Figure 5.4-6. Bosch Type Injector in 1Y73 Cylinder Head

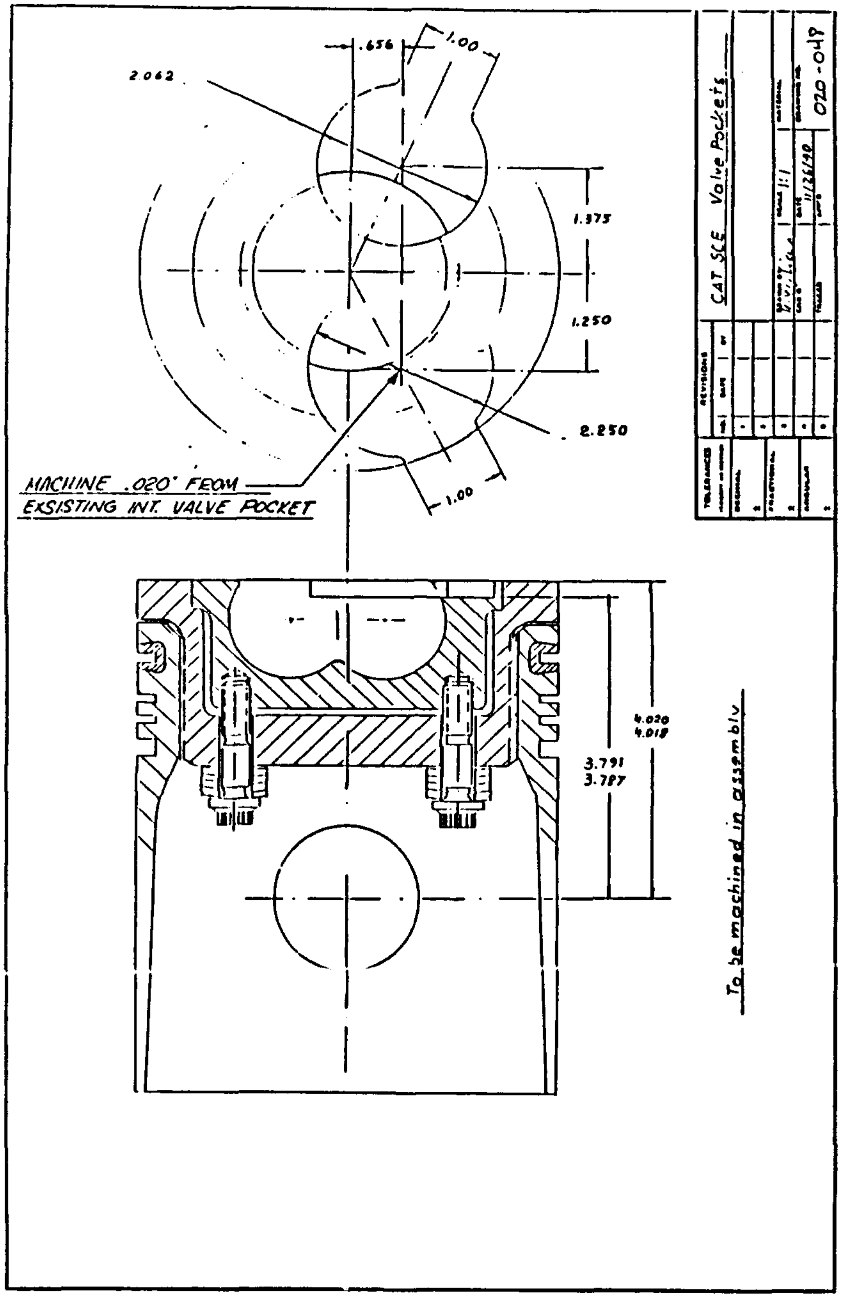

Figure 5.5-1. Three Piece Piston Design

relative thermal expansion between the various components. This required the use of four bolts to hold the chamber in place (the press-fit could not be relied upon to hold the chamber) and required the use of belleville type spring washers to maintain the bolt load at all conditions. To reduce the amount of heat flow from the TICS chamber to the carrier, the press-fit area was minimized and an air-gap was maintained between the top of the aluminum skirt portion of the piston and the carrier. To reduce heat conduction down the bolts, the bolts were made as long as possible. An alternative TICS chamber (Figure 5.5-2) was designed utilizing a low thermal conductivity titanium material with a thermal barrier coating as a further means of insulating the piston. This design was never fabricated.

The second piston design was for use with the precombustion chamber type TICS concept. Two standard Caterpillar 1Y73 pistons were designed to be modified to accept thermal barrier coatings on the combustion chamber surface. One of the pistons (Figure 5.5-3) was per the standard Caterpillar 1Y73 configuration and the second (Figure 5.5-4) raised the upper surface to reduce the clearance volume for use with the large volume TICS precombustion chamber. Various types of thermal barrier coatings were used on the pistons including both densified and undensified plasma sprayed partially stabilized zirconia and several proprietary (Adiabatics) slurry type ceramic coatings. All of the coatings were designed to be approximately 0.030 inch thick.

The cylinder head including the intake and exhaust ports and the intake and exhaust valve faces were designed to be coated with a thermal barrier coating on the combustion and inner port surfaces. A 0.030 inch thick coating of partially stabilized zirconia was applied to the surfaces and the coating was densified with a proprietary coating sealer developed by Adiabatics.

Two types of coated cylinder liners were designed for this project. The first was a conventional liner with a thin chrome oxide type coating, which does more to improve the high temperature tribology than to provide insulation. This technology has proven effective on other uncooled engines [5,6] and allows the liner to run without cooling. A second approach was also designed for this project as it was anticipated that the in-cylinder temperatures would be significantly higher at stoichiometric conditions. This liner consisted of using a water-cooled liner that was coated with a thermal barrier (0.030 inch thick zirconia) only for the top 4 inches. The theory behind this concept was to reduce the heat transfer during the combustion portion of the cycle and also allow the ring surface to be cooled while the piston was on the bottom portion of its stroke.

Two types of insulated TICS precombustion chambers were designed. The first was to use a material for the chamber which would withstand continuous high temperature operation and simply run the engine with no cooling to the prechamber area. Based on past experience this works but

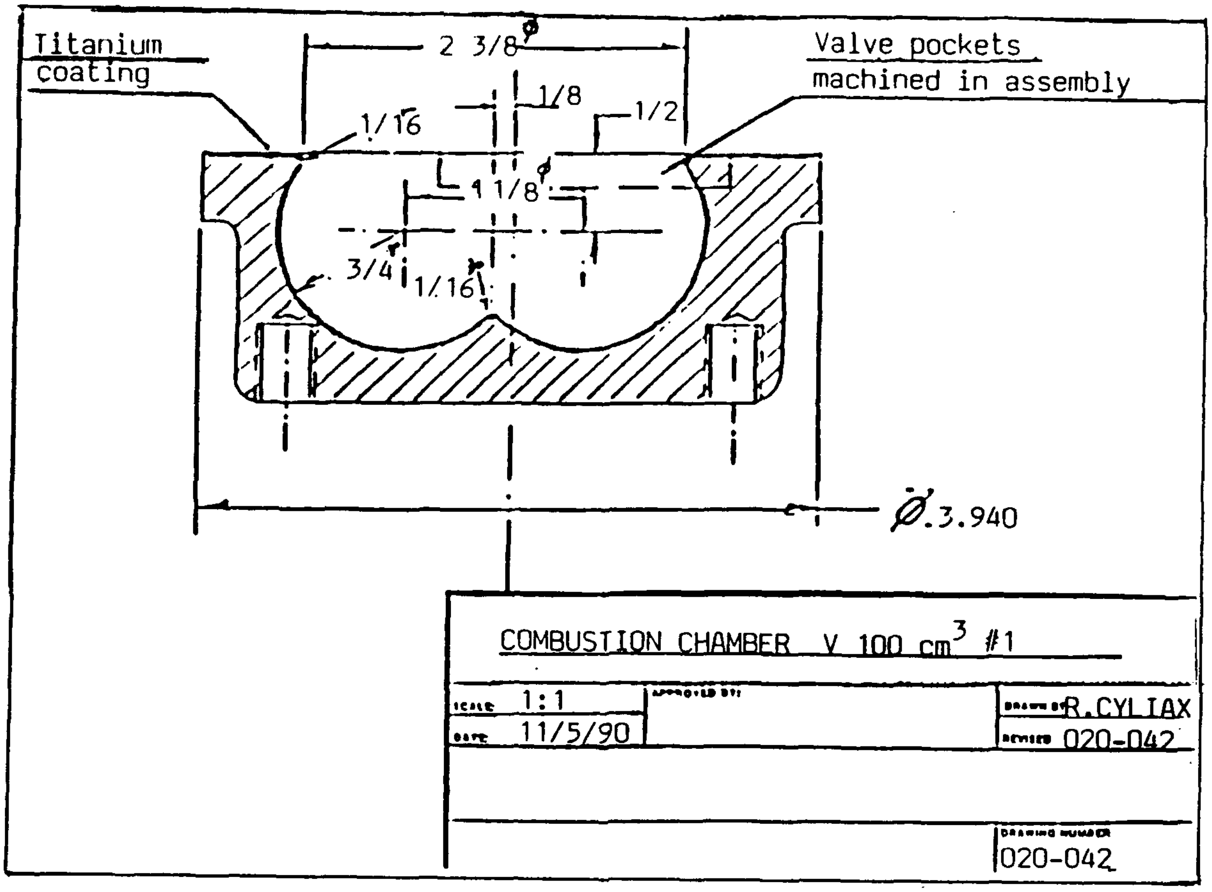

Figure 5.5-2. Bowl #2 - Titanium with Thermal Coating

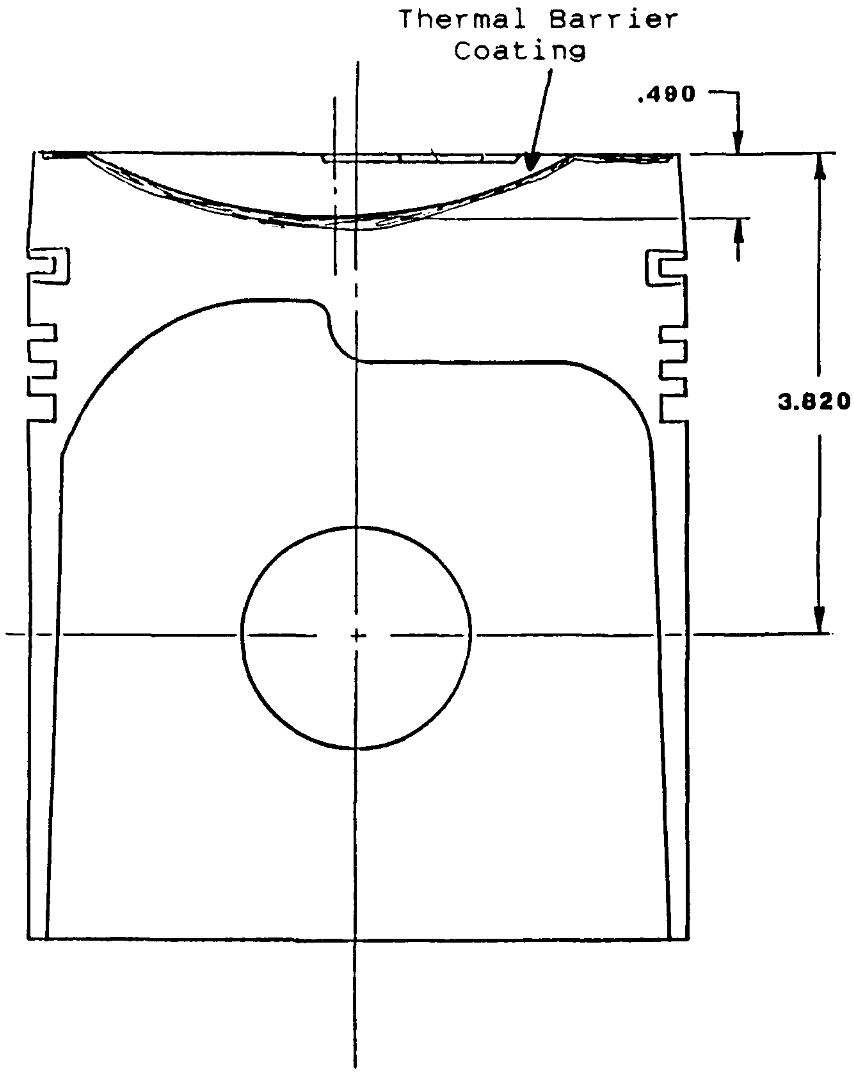

Figure 5.5-3. Piston #1 - Stock Clearance Volume

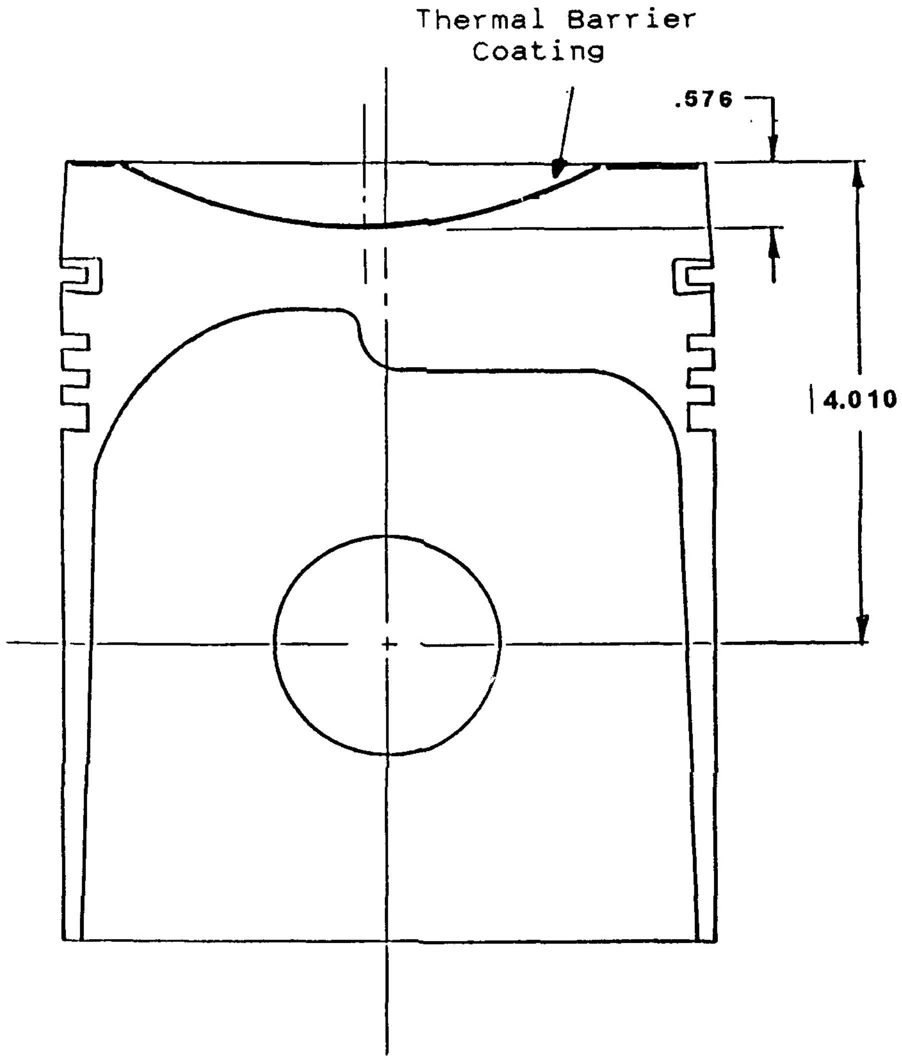

Figure 5.5-4. Piston #2 - For 50% Volume Ratio TICS Chamber

invariably leads to failures of the cylinder head where the chamber attaches. Therefore, a second design (shown in Figure 5.4-5) was made that utilizes water-cooling of the cylinder head area around the precombustion chamber to prevent head cracking and utilizes captive air-gaps machined into the TICS precombustion chamber walls to provide insulation.

5.6. Task IV - Procurement of Components

As previously described three different test engines were obtained for this program as follows:

MODEL	MAKE	FIGURE #	SOURCE	COST
V6-200	Cummins	5.6-1	MIT/Sandia	Loan
NH-1	Cummins	5.6-2	Adiabatics	Loan
1Y73	Caterpillar	5.6-3	Southwest Research	$5,750

The Caterpillar 1Y73 single cylinder precombustion chamber type diesel oil test engine was used for all of the testing. The specifications for the engine are as follows:

MODEL	Caterpillar 1Y73
BORE	5-1/8 inches
STROKE	6-1/2 inches
DISPLACEMENT	134.1 cubic inches
RATED SPEED	1800 rpm
RATED BMEP	151 psi
RATED POWER	46 horsepower
RATED INTAKE TEMPERATURE	253 ^{O} F.
RATED INTAKE PRESSURE	53 in. Hg. Abs.
RATED EXHAUST TEMPERATURE	1300 ^{O} F.
RATED FUEL CONSUMPTION	22.1 lbs/hr
RATED SPECIFIC FUEL CONSUMPTION	0.480 lbs/Bhp-hr

The details concerning the remaining equipment and the hardware procured for this program are elaborated upon in the Test Plan Appendix A).

5.7. Task V - Test Preparation

The 1Y73 engine was installed in a new test cell constructed especially for this program by Adiabatics. A used 250 horsepower Midwest eddy current type dynamometer and dynamometer controller were purchased to absorb the engine load, measure, and control both speed and load. A used cast iron bedplate was cleaned and cast into a reinforced concrete inertia block and set on rubber vibration isolators to provide a stiff mounting bed for the engine and dynamometer. A special twin universal joint driveshaft with a splined internal shaft for axial misalignment was used to couple the engine and dynamometer. A 50 horsepower Ingersoll Rand screw type air compressor was purchased to provide pressurized air to the engine. The dry and oil free air from the

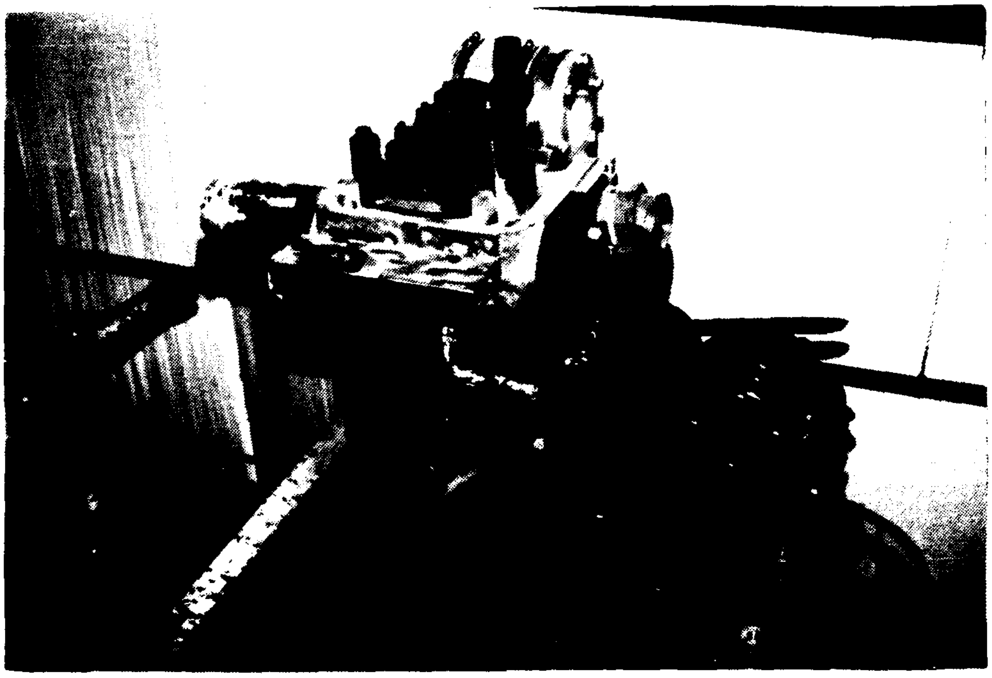

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Figure 5.6-1. V6-200 Engine VIM

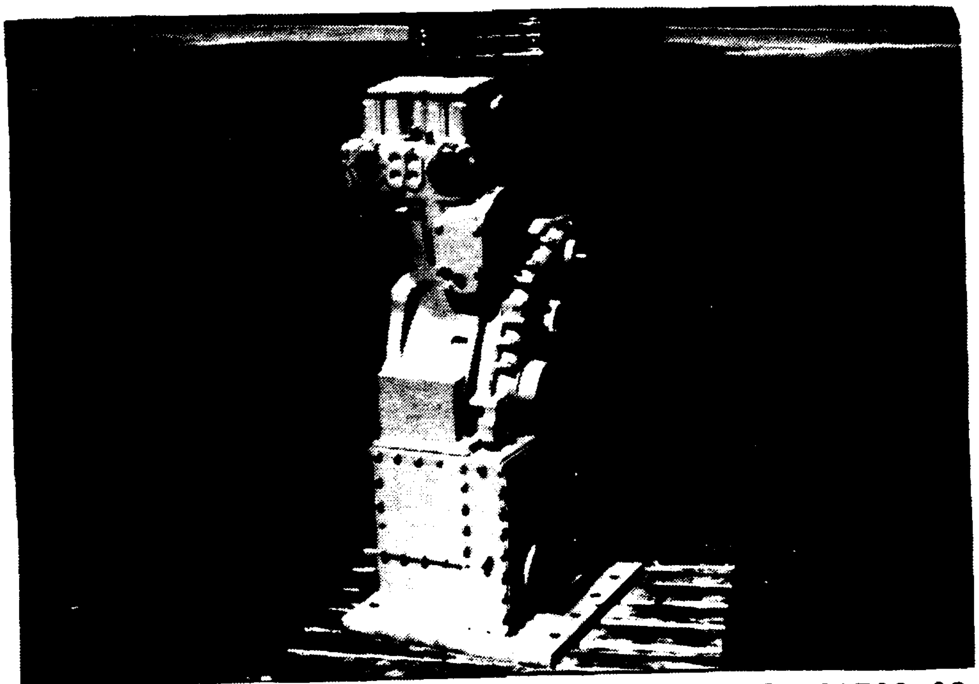

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Figure 5.6-2. NH Single Cylinder Engine

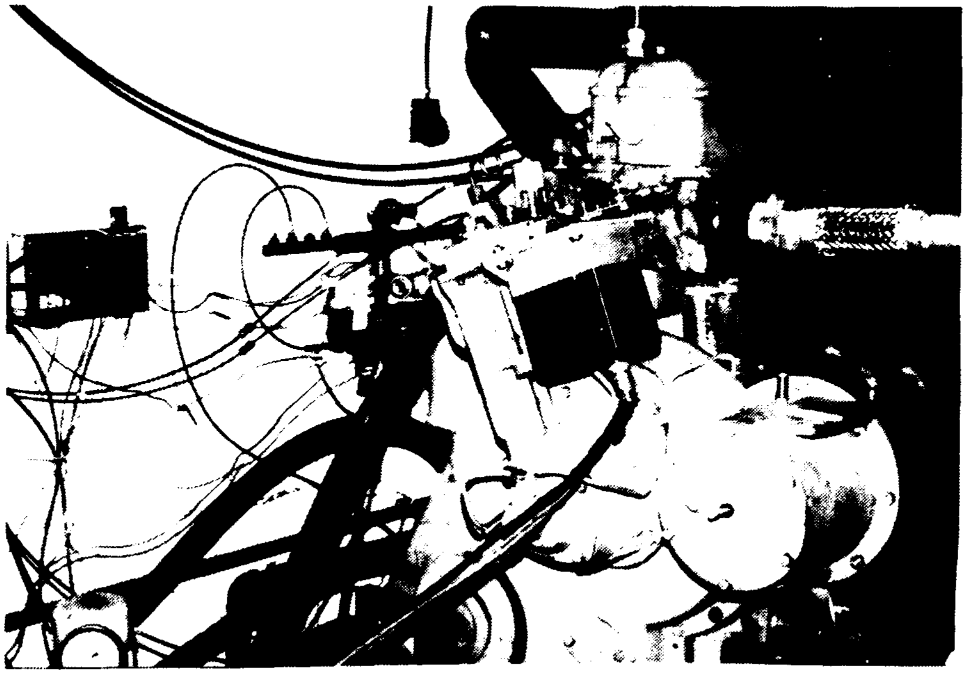
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Figure 5.6-3. CAT Engine

compressor is supplied to the engine through a pressure reducing valve (Figure 5.7-1) to an orifice type flowmeter to an electric air heater to the intake surge tank (Figure 5.7-2). The engine exhaust back pressure is controlled by a manually adjustable butterfly valve and supplied to the silencer (Figure 5.7-3). Exhaust smoke is sampled by an AVL sampling type smokemeter prior to the butterfly valve. Lubricating oil is provided to the engine by a new external lubrication system with electric motor driven oil pumps (Figure 5.7-4). A new engine control panel was designed and fabricated to mount all of the monitoring and control instruments and readouts (Figure 5.7-5).

Figures 5.7-6 and 5.7-7 show the installation of the fuel pump with timing device and injector, respectively. The high pressure fuel injection line was instrumented to measure injection line pressure and the injector was instrumented to measure needle lift.

Engine cylinder pressure was measured with a water cooled piezoelectric type transducer coupled to a charge amplifier. Crankangle position was measured with an optical encoder mounted on the end of the crankshaft and carefully aligned to actual top-dead-center piston position. Cylinder pressure was recorded on both a Nicolet digital oscilloscope and a high speed computerized data acquisition system which recorded cylinder pressure every crank degree as indicated by the encoder for a total of 100 cycles (200 engine revolutions). A software package was then utilized to average the pressure signals over the 100 cycles and provide an average pressure history for subsequent analysis to determine instantaneous rates of pressure rise and heat release.

5.8. Task VI - Testing

Actual engine testing, following engine and test cell shakedown running and breaking in of the engine started on January 23, 1991. A copy of the logsheet which was filled out for each test point is shown as Figure 5.8-1. The logsheet data was entered into a spreadsheet program daily for analysis and ease of graphing. A copy of this spreadsheet is attached to this report as Appendix B.

As shown on the logsheet printout the engine was run with eighteen separate build configurations described as follows:

5.8.1. Build I. The initial build of the engine was in the stock Caterpillar configuration with normal water cooling of the head and block (liner). All standard parts including the stock precombustion chamber and Caterpillar fuel pump, line and nozzle were used. Ten data points were taken in this configuration to verify proper engine and test cell performance. Figure 5.8.1-1 is a copy of a performance curve for the 1Y73 engine which was obtained from Caterpillar. The first series of tests which we ran (points 1 through 9) were an attempt to duplicate the operating conditions specified on this graph. The data points plotted on the curves are the results of our engine test. The two parameters which we could measure and plot on this curve were exhaust

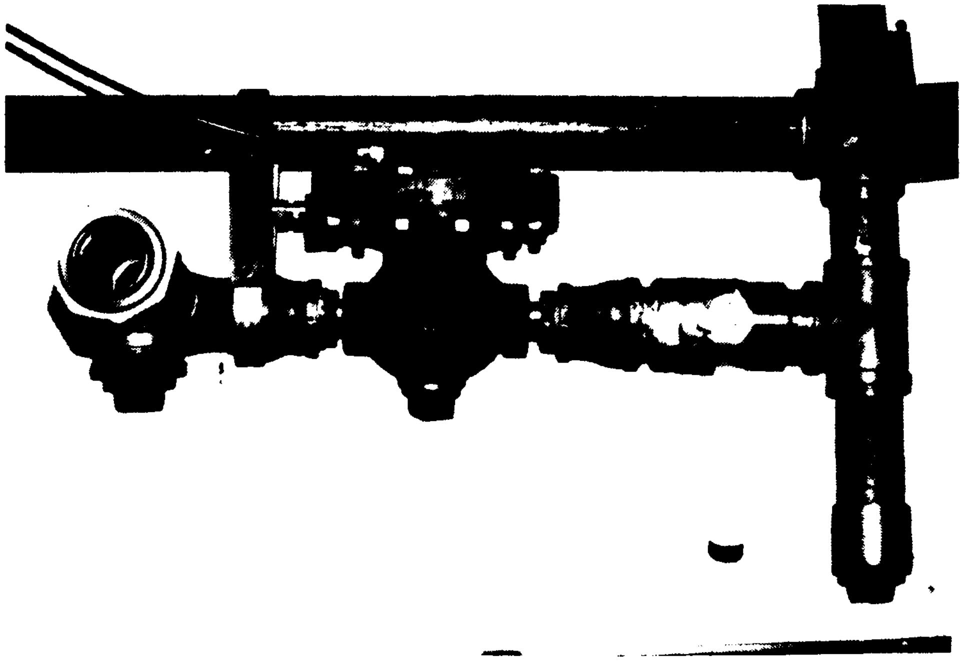

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Figure 5.7-1. Intake Pressure Control Valve

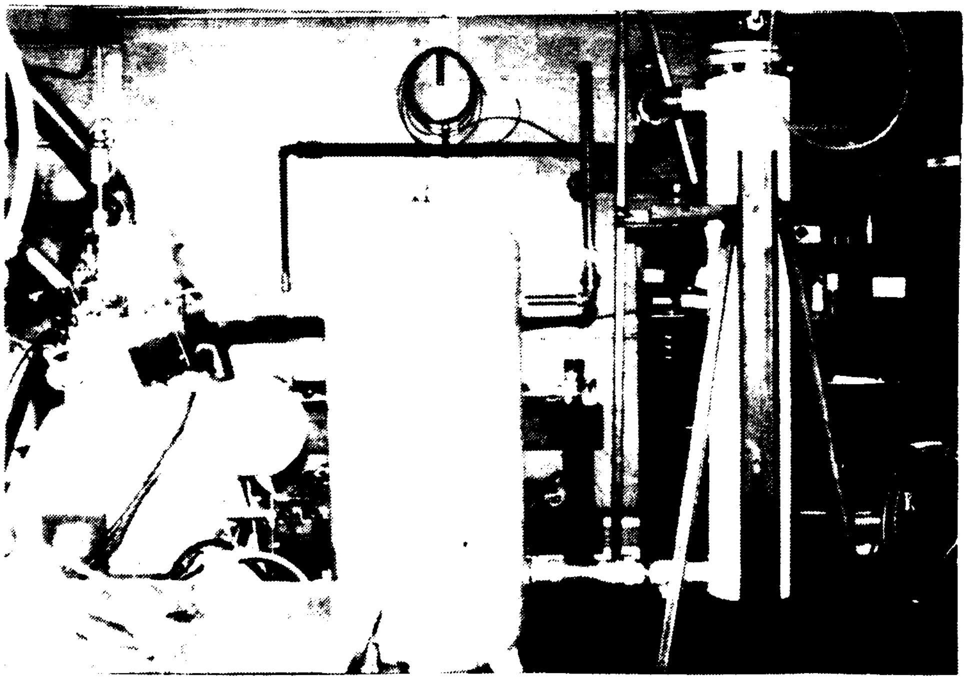

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Figure 5.7-2. Engine, Intake Surge Tank, Heater

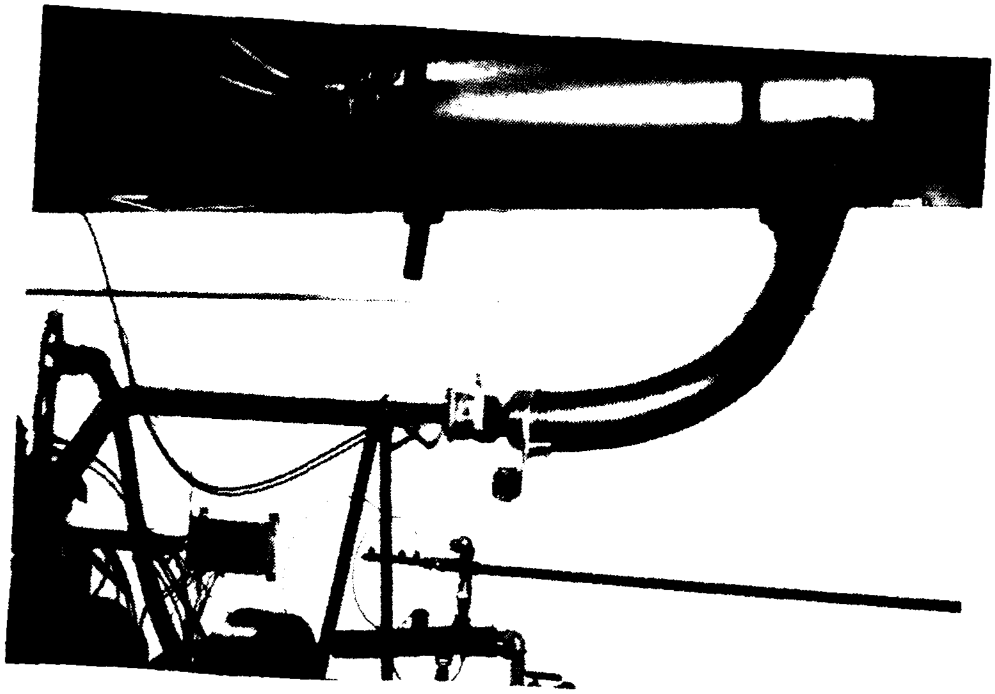

Figure 5.7-3. Exhaust Header - Muffler, Restrictor AI-224-4a

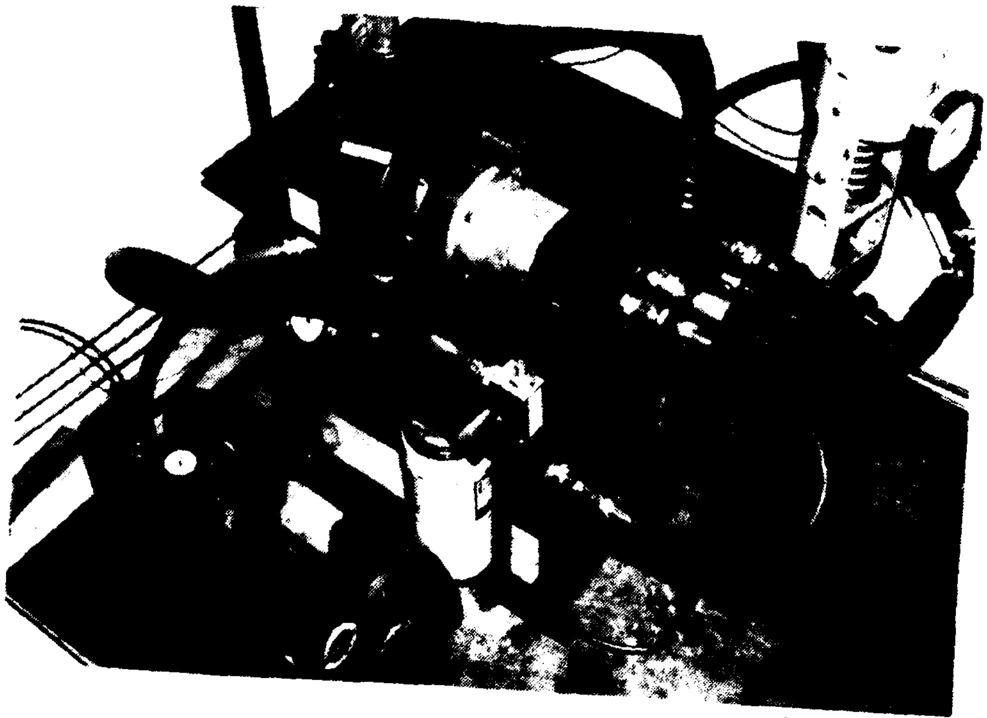

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Figure 5.7-4. Oil Pumps and Cooler

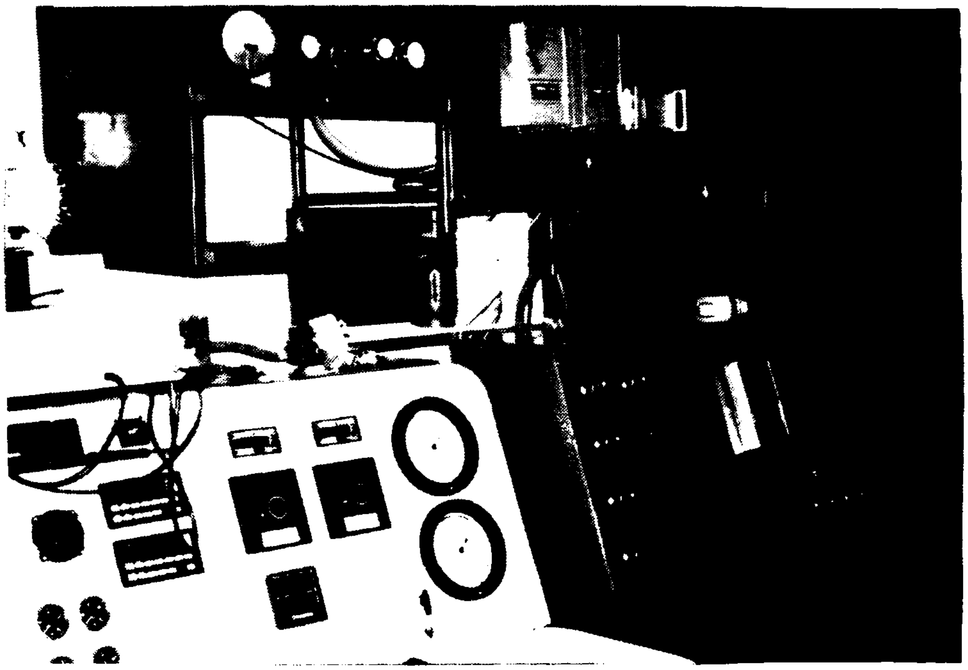

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Figure 5.7-5. Control Console Panel

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Figure 5.7-6. Fuel Pump Installation

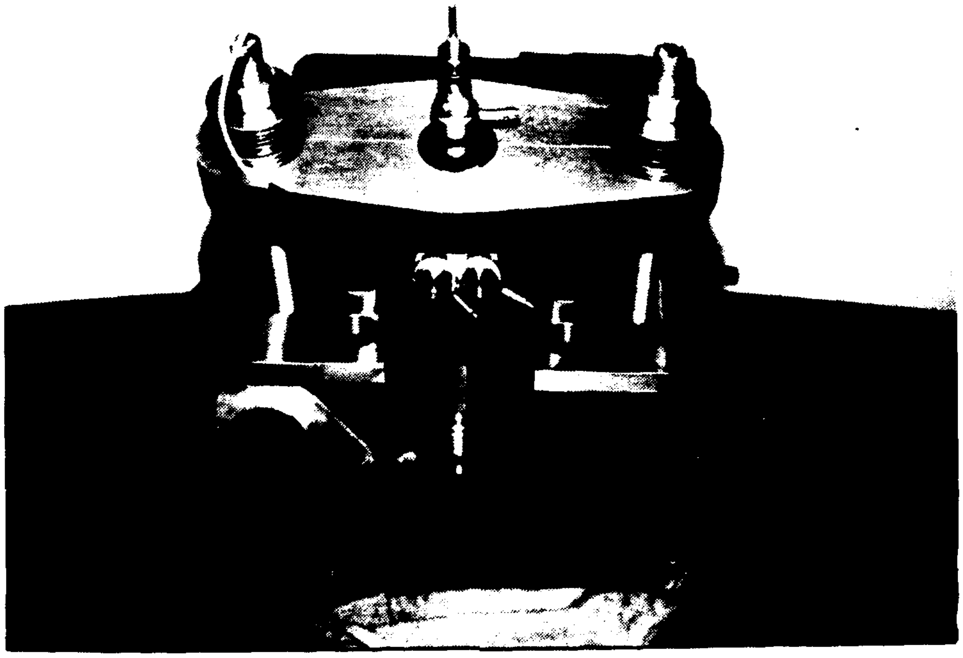

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Figure 5.7.7. Installed Injector

STOICHIOMETRIC TEST DATA - 1Y73			
DATE:	TIME:		BUILD:
TEMPERATURES (F)			
OIL RESERVOIR			
OIL FILTER			
TRANS/INJ COOLANT			
OIL COOLER WATER-OUT			
ENGINE WATER-IN			
OIL PAN			
OIL TO BEARINGS			
ENGINE WATER-OUT			
INTAKE HEATER-OUT			
[illegible]UTED WATER-RETURN			
DYNO WATER-OUT			
TEST CELL AMBIENT			
HEATER CONTROLLER (OUT)			
HTR CONTROLLER SET PT			
OIL SYSTEM (CONSOLE)			
ORIFICE METER			
INTAKE SURGE TANK			
PC TEMPERATURE			
EXHAUST			
PRESSURES			
INTAKE SURGE TANK (PSIG)			
ORIFICE METER (PSIG)			
EXHAUST (IN Hg)			
ORIFICE DELTA P (IN H2O)			
LUBE (PSIG)			
SYSTEM			
HEAD			
PISTON COOLING			
CRANKCASE			
PERFORMANCE			
COOLING (PSIG)			
BLOW-BY (IN H2O)			
FUEL LINE (PSIG)			
FUEL TRANSFER (PSIG)			
LOAD (FT-LB)			
RPM			
FUEL SCALE TIMER (MIN)			
FUEL SCALE COUNTER			
WT. FUEL CONSUMED (LB.)			
PEAK PRESSURE (mV)			
BAROMETER (IN Hg)			
% HUMIDITY			
CYLINDER PRESSURE FILE			
NICOLET FILE			
SMOKE			
TIMING			
DURATION			
TIME			
INJECTION PRESSURE			

Figure 5.8-1 Stoichiometric Test Data - 1Y73

DATE: 5 DEC 198[illegible]

CATERPILLAR TRACTOR CO. ENGINE DIVISION ENGINEERING

CALIBRATION CURVES

1 Cyl. 5.125 X 6.5 Test Engine Arrangement 1Y73 Serial No. 37Z00017

For

Engine Speed	1800 RPM	Barometer	29.7 In. Hg.
Inlet Air Press.	53.0 In. Hg. Abs.	Outlet Water Temp.	189-190 °F
Inlet Air Temp.	254-256 °F	Oil-to-Brgs. Temp.	205-206 °F

With Fuel Rack in Shut-Off Position Micrometer Reading Is —.243 Inch

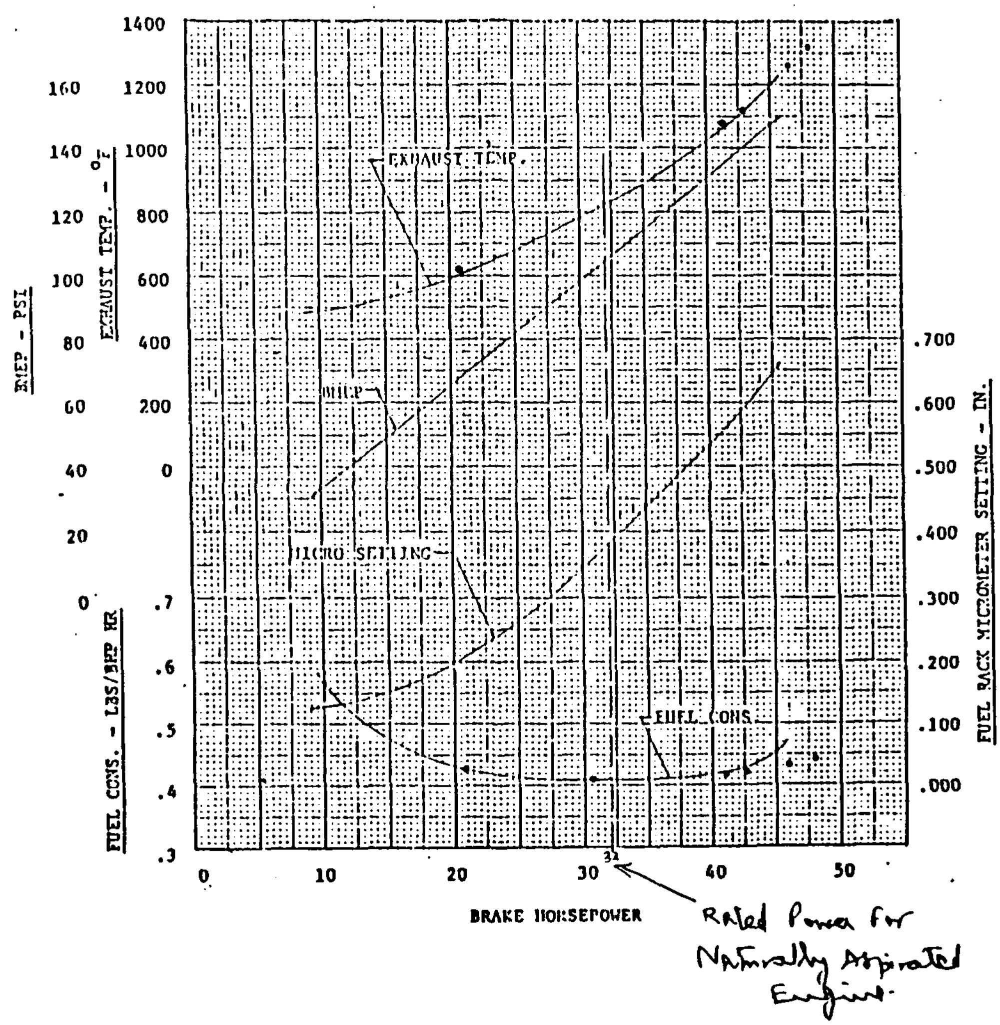

Figure 5.8.1-1. Calibration Curves

temperature and specific fuel consumption. Examination of the graph shows that our engine test very closely duplicated the Caterpillar results and confirms that the engine and basic instrumentation including load and fuel flow are working properly. Point number 10 differs from the other baseline engine points in that it was run with restricted exhaust flow so that exhaust and intake pressures are equal; whereas, the first nine points were run with no exhaust restriction per the Caterpillar test method. All of the following stoichiometric test data were also taken with the exhaust restricted to equalize intake and exhaust pressures so that there is no pressure drop across the engine. This was done to make it unnecessary to correct the data for the effect of this variable on performance.

5.8.2. Build II A, B & C. The first stoichiometric builds were with the TICS chamber in the piston using the Hastelloy Bowl #1 configuration. Figure 5.8.2-1 is a photograph of the assembled piston prior to test and Figure 5.8.2-1 is a photograph after test showing the combustion pattern discoloration of the surface. Figure 5.8.2-3 is a bottom view of the piston showing two of the bolts holding the bowl in place. Figure 5.8.2-4 shows the piston disassembled after the test. The difference between builds IIA and IIB was a change from a four hole to a six hole injector nozzle. Figure 5.8.2-5 is a photograph of the combustion surface of the cylinder head showing the thermal barrier coating and the retention of the valve seat inserts by staking. The picture shows the intake (larger) valve, exhaust valve (smaller), and the fuel injector locations.

The piston was modified two times during the testing that resulted in three Build identifications A, B and C. Build B incorporated design changes to improve the retention of the bowl and improve the pinning of the bowl retainer to prevent the retainer from unscrewing and loosening during operation. Build C increased the depth of the intake valve pocket to prevent interference with the intake valve.

Figure 5.8.2-6 is a plot of Brake Mean Effective Pressure (BMEP) versus Air Fuel Ratio (A/F) for the baseline (Build I) and TICS chamber in the piston testing. The baseline test was run per the Caterpillar Test Specifications previously described including running at constant intake manifold pressure and no artificial exhaust restriction. The data for this test (shown as Build I) shows that the power increases virtually linearly as the air fuel ratio decreases (as more fuel is added) down to a fuel air ratio of about 19 to 1. Point 10 shows the power lost due to restriction of the exhaust flow at a 20 to 1 air fuel ratio. The data with the TICS chamber piston was run with richer (lower air fuel ratio) mixtures and reached a BMEP of only 100 psi. Figure 5.8.2-7 is a plot of brake specific fuel consumption for builds I and II as a function of brake mean effective pressure. The first nine points of the baseline Build I data show a classic fish-hook shape curve with a minimum of 0.400 lbs/bhp-hr at a BMEP of 137 psi. The single point taken with the baseline configuration with the exhaust restricted to match intake pressure is shown as Point 10. This data will be shown on all of the

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Figure 5.8.2-1. Assembled Three Piece Piston

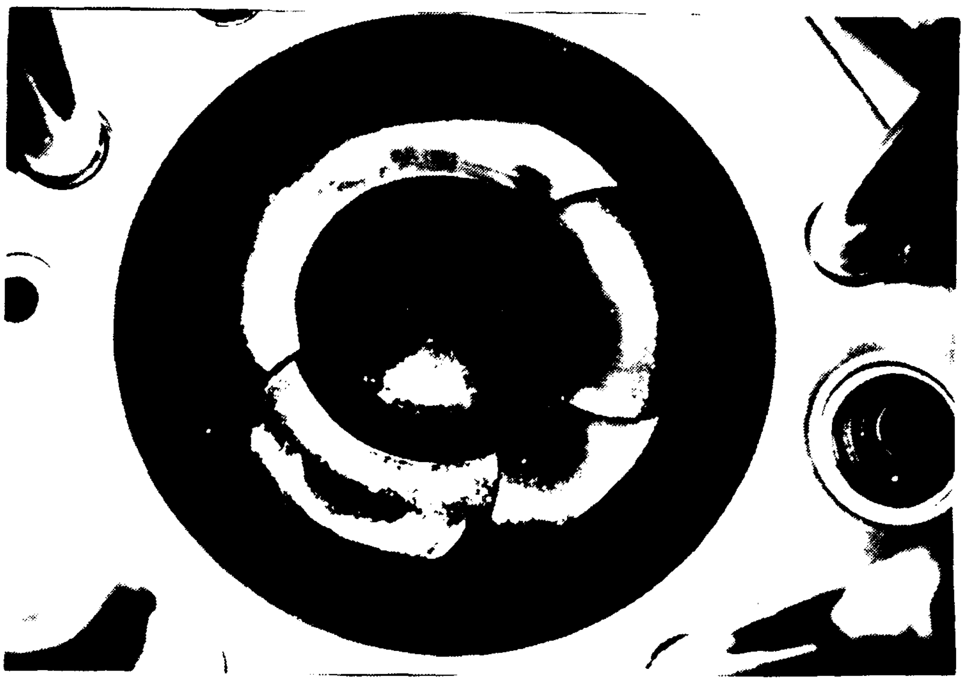

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Figure 5.8.2-2. Three Piece Piston - Deposits Show Hot Spots

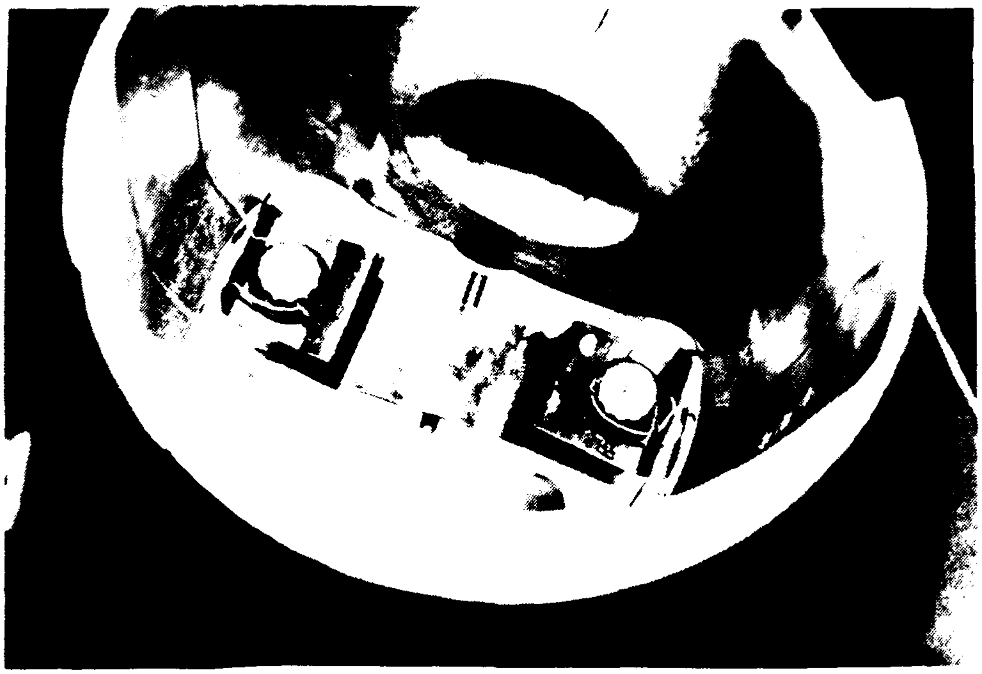

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Figure 5.8.2-3. Three Piece Piston - Bottom View

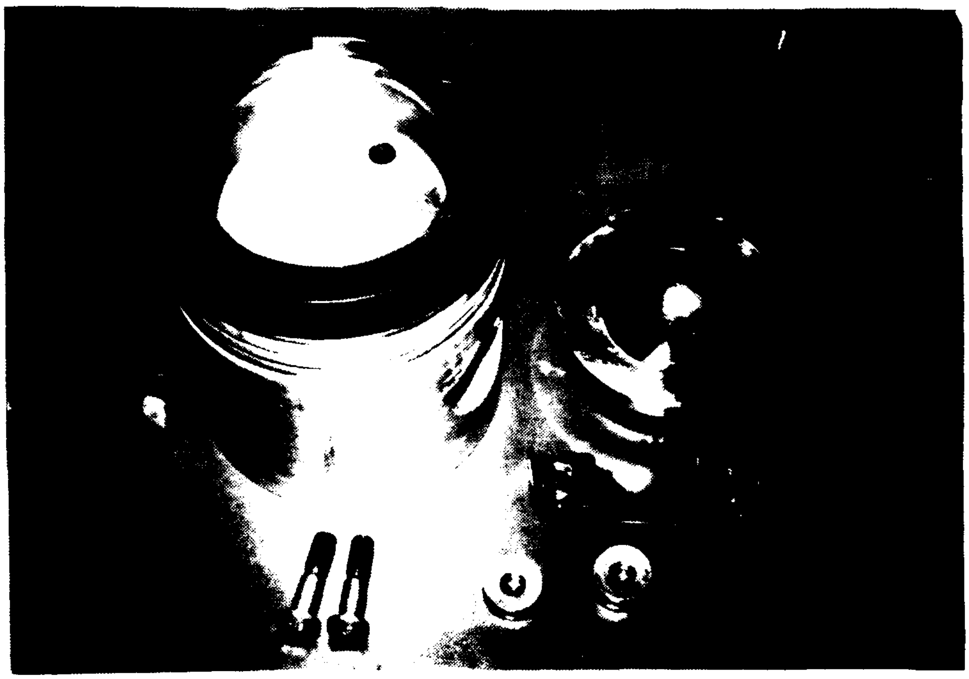

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Figure 5.8.2-4. Three Piece Piston - Disassembled, and Used

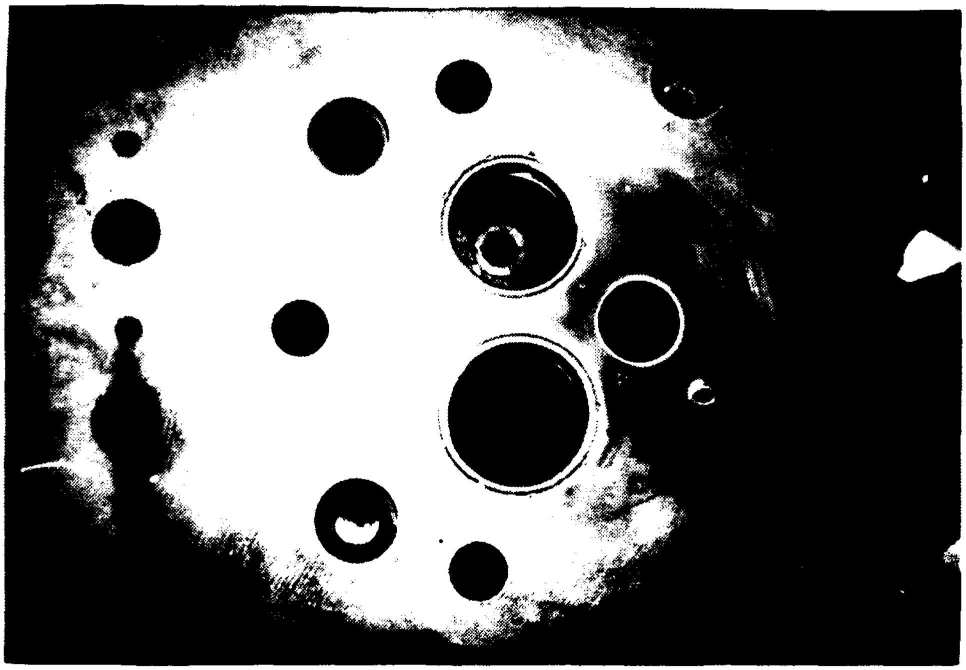

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Figure 5.8.2-5. Cylinder Head - New, Shows Staking

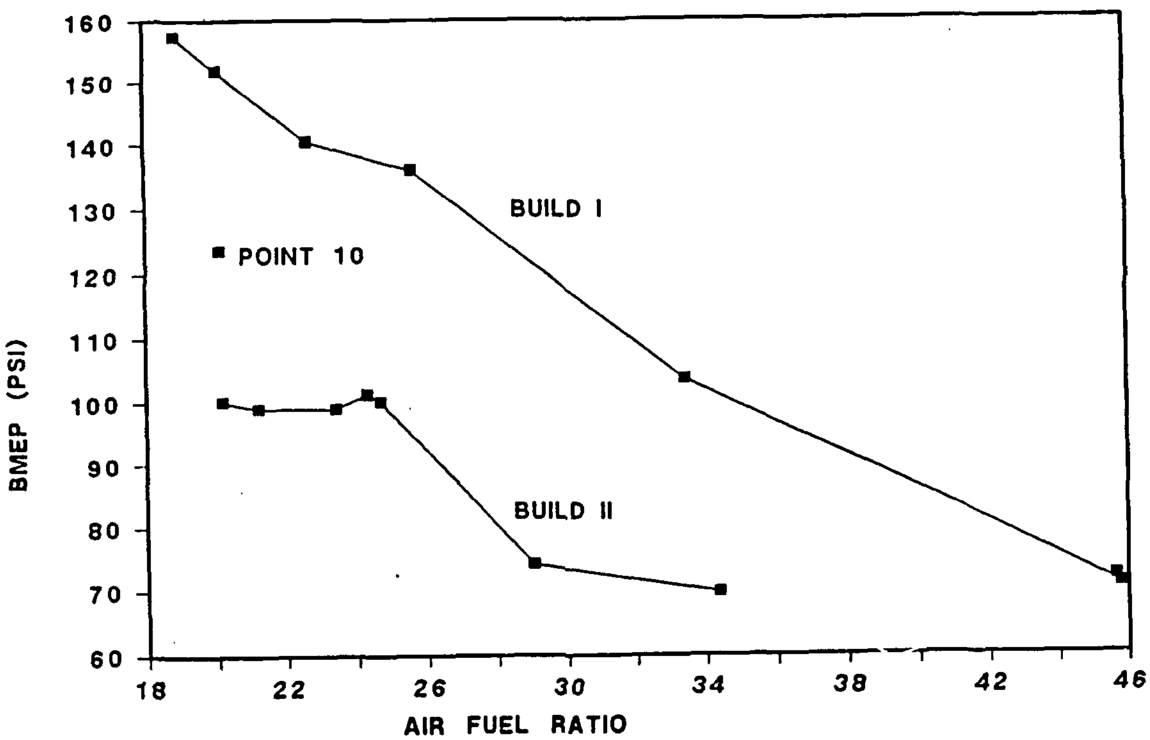

Figure 5.8.2-6 BMEP vs. A/F, Build I and Build II

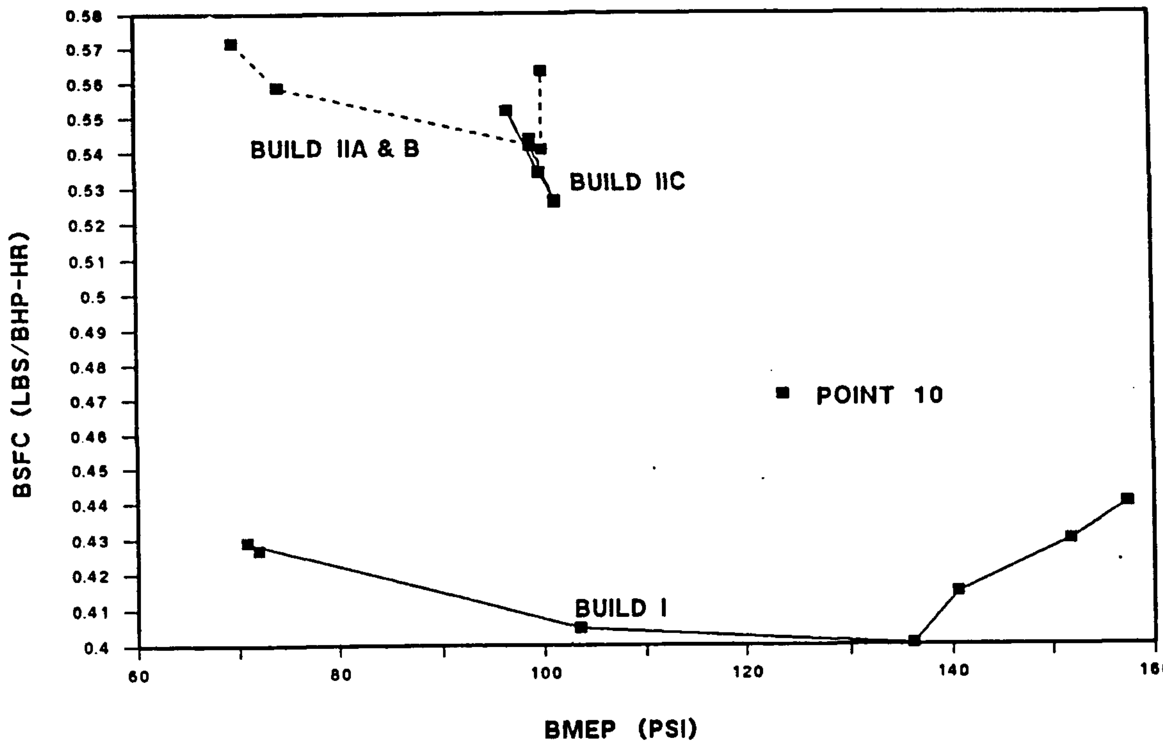

Figure 5.8.2-7 BSFC vs. BMEP, Build I and Build II

plots for each test series for comparison purposes. The TICS chamber in the piston data for Builds II A, B and C show significantly higher fuel consumption at the light loads where they were tested. Figure 5.8.2-8 shows the specific fuel consumption versus air fuel ratio for the same data points. Figure 5.8.2-9 shows the smoke versus air fuel ratio performance for the baseline and TICS chamber piston runs. The baseline engine including Point 10 had extremely low smoke levels at all mixture strengths and loads whereas the TICS chamber piston had very high smoke levels. For reference purposes a Bosch smoke reading of 2.0 to 2.5 is considered the threshold of visibility.

Based upon these test results it was decided that the prechamber type TICS approach would be utilized for the remaining testing and the piston bowl approach would be dropped from the test matrix.

5.8.3. Build VI A, B, C, D & E. Build VI started testing of an uncooled engine configuration with a TICS precombustion chamber. The engine had a prechamber which was of slightly larger volume than the standard Caterpillar prechamber (47 versus 41 cubic centimeters) which resulted in a lower compression ratio (14.4 versus 16.5). The six different Builds were the result of changes to improve the prechamber sealing and with cooling to different parts of the engine (i.e. block and head). Figure 5.8.3-1 is a photograph of the injector and TICS chamber and Figure 5.8.3-2 is a picture of the coated piston bowl.

Figure 5.8.3-3 is a plot of BMEP versus F/A for the baseline and Build VI. The testing was run at very rich air fuel ratios bracketing the stoichiometric range and proceeding toward the vicinity of the baseline Point 10. Figure 5.8.3-4 is the fuel consumption versus BMEP for this data. This curve shows that the engine performed virtually identically to the baseline engine and achieved equal fuel economy at the same load. Figure 5.8.3-5 shows the fuel economy versus A/F. Examination of this plot shows that the fuel economy of the stoichiometric engine degrades sharply as the air fuel ratio approaches stoichiometric and is about 10 percent worse than the baseline engine at 20:1 air fuel ratio. Some of this loss is obviously the result of decreased compression ratio. Figure 5.8.3-6 shows that the smoke performance of the engine paralleled the fuel consumption performance. At air fuel ratios over 18 the TICS chamber engine had low smoke levels which would not be visible.

5.8.4. Build VII A ,B, C & D. Build VII consisted of a new precombustion chamber which was designed with internal air-gap insulation to enable running with water-cooling to the cylinder head to prevent head cracking. A typical head which had cracked during the Build VI testing is shown as Figure 5.8.4-1. This type of failure was becoming routine when attempting to run near stoichiometric conditions and the choices were either designing a new cylinder head that could run without cooling or revert to cooling. The latter method was selected. Figure 5.8.4-2 shows the new TICS chamber designed with a spacer which allowed the volume of the chamber to be either 84 or 34 cubic centimeters depending upon whether the spacer is used. With the 84 cc

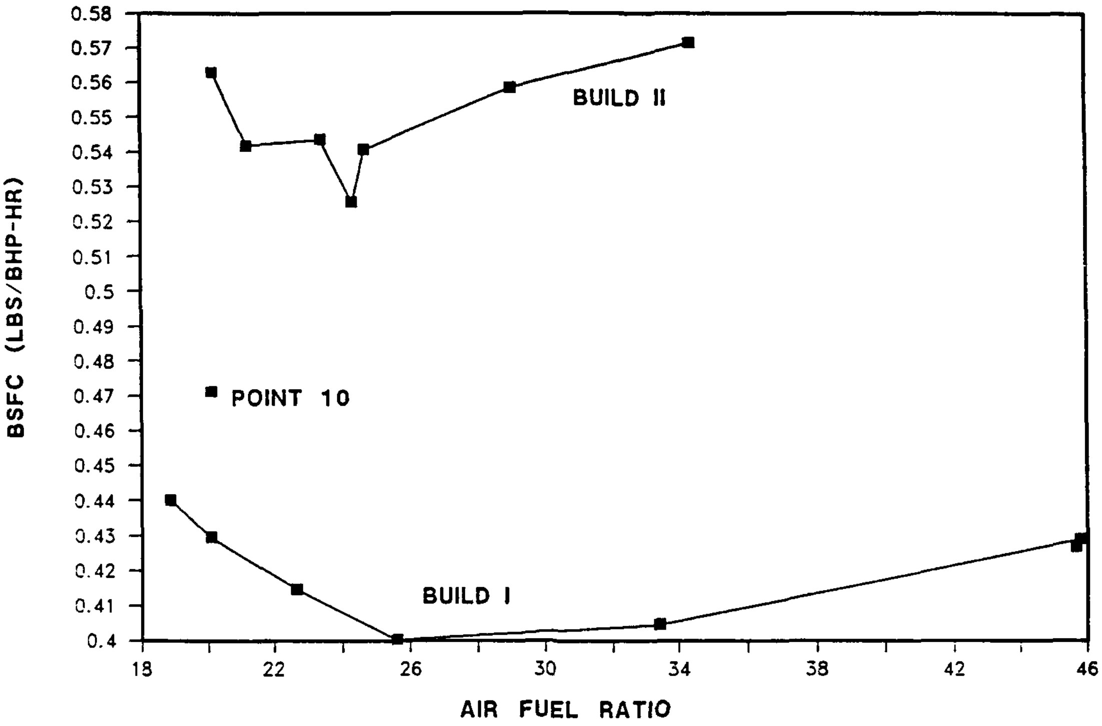

Figure 5.8.2-8. BSFC vs. A/F, Build I and Build II

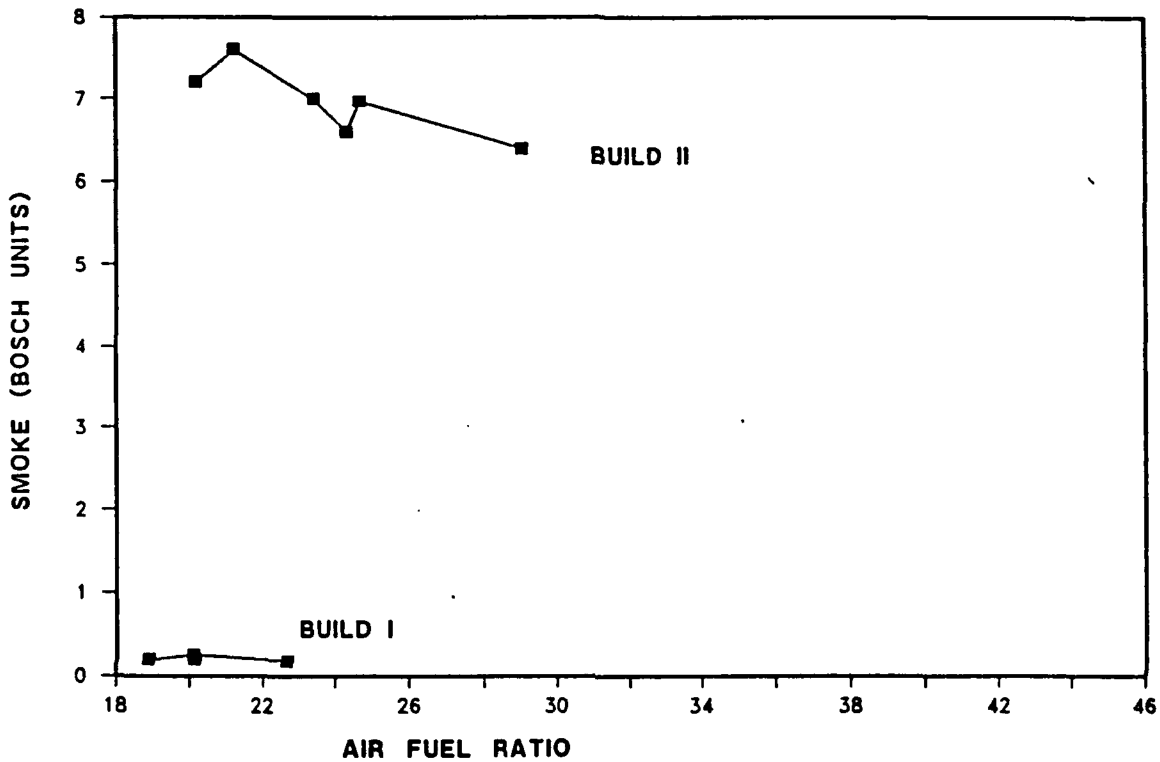

Figure 5.8.2-9 Smoke vs. A/F, Build I and Build II

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Figure 5.8.3-1. Fuel Injector and PCC

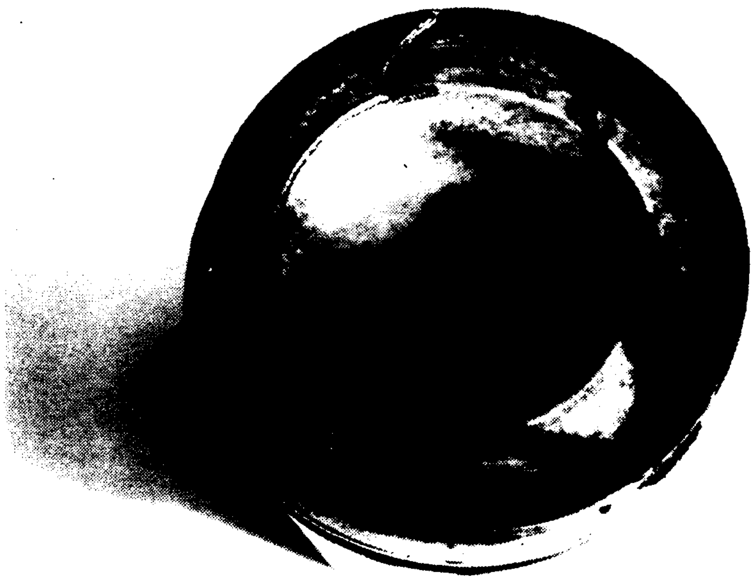

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Figure 5.8.3-2. Coated Standard Piston

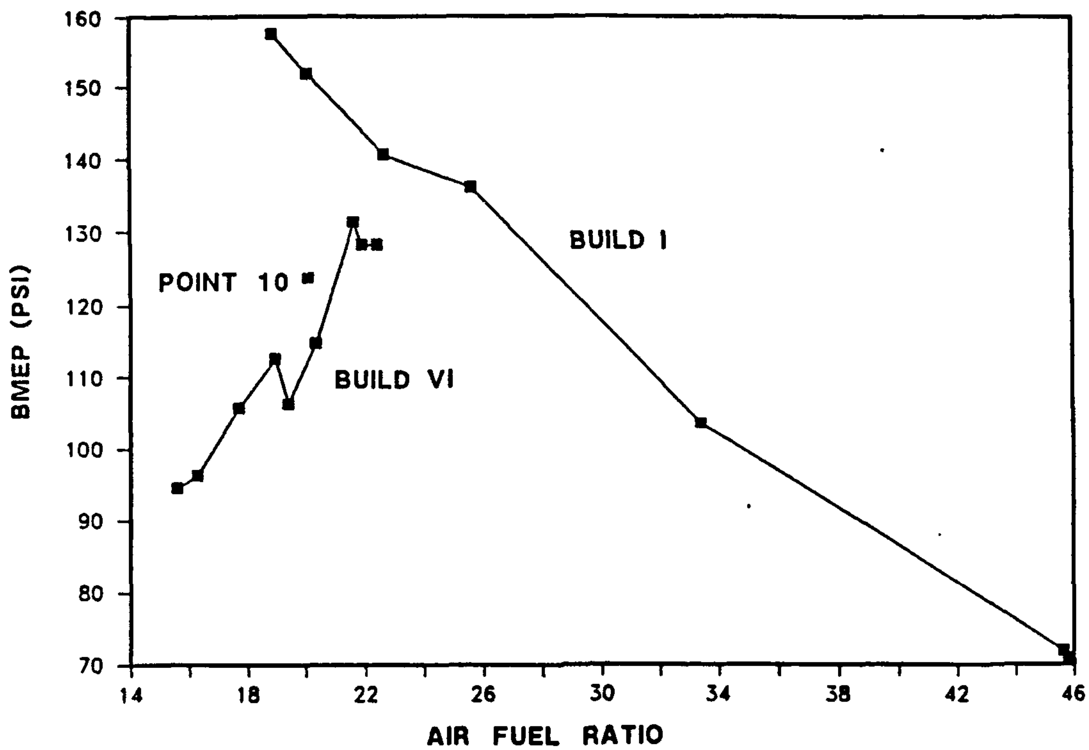

Figure 5.8.3-3 BMEP vs. A/F, Build I and Build VI

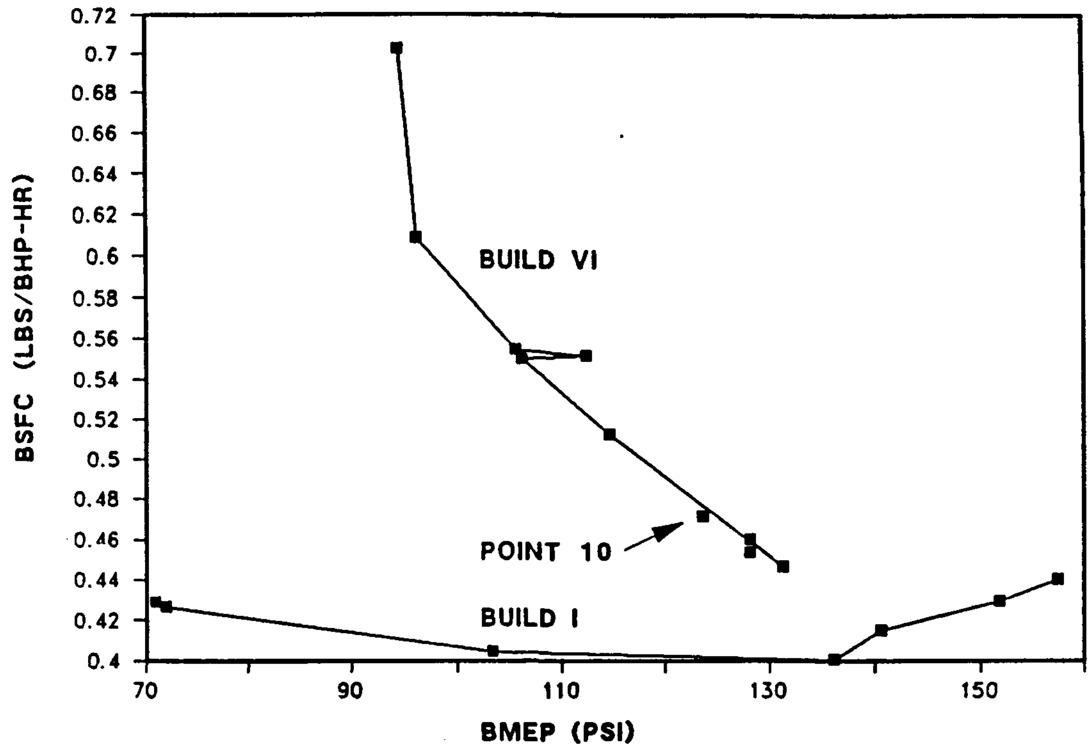

Figure 5.8.3-4 BSFC vs. BMEP, Build I and Build VI

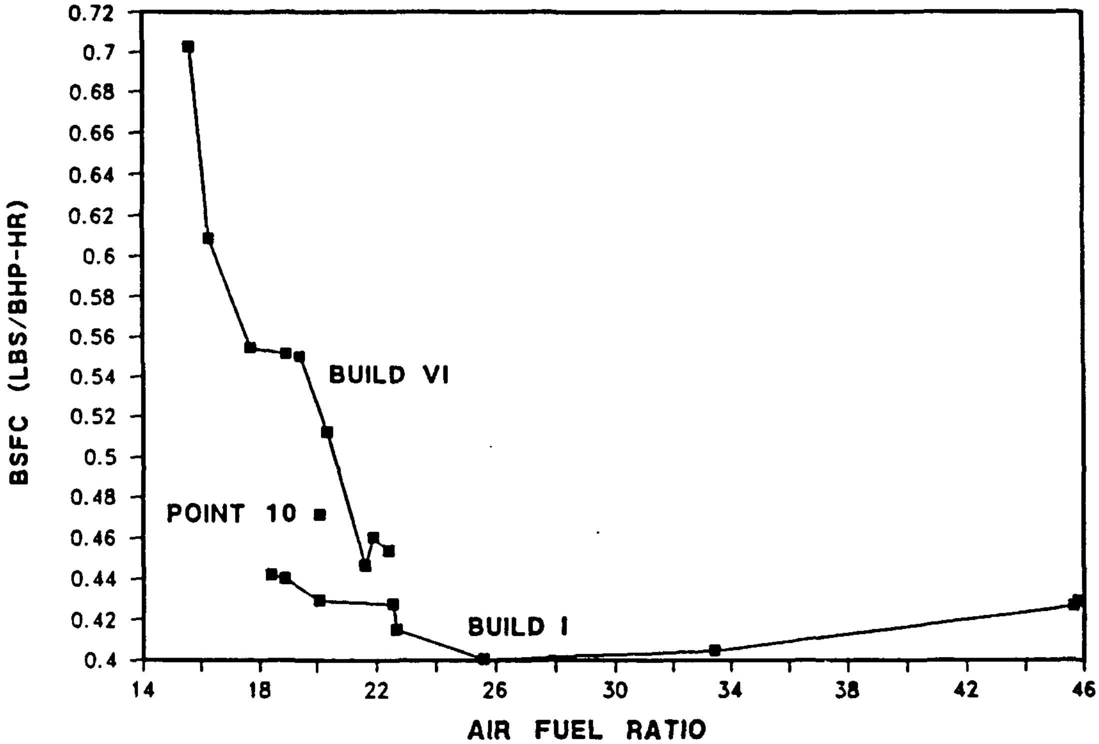

Figure 5.8.3-5 BSFC vs. A/F, Build I and Build VI

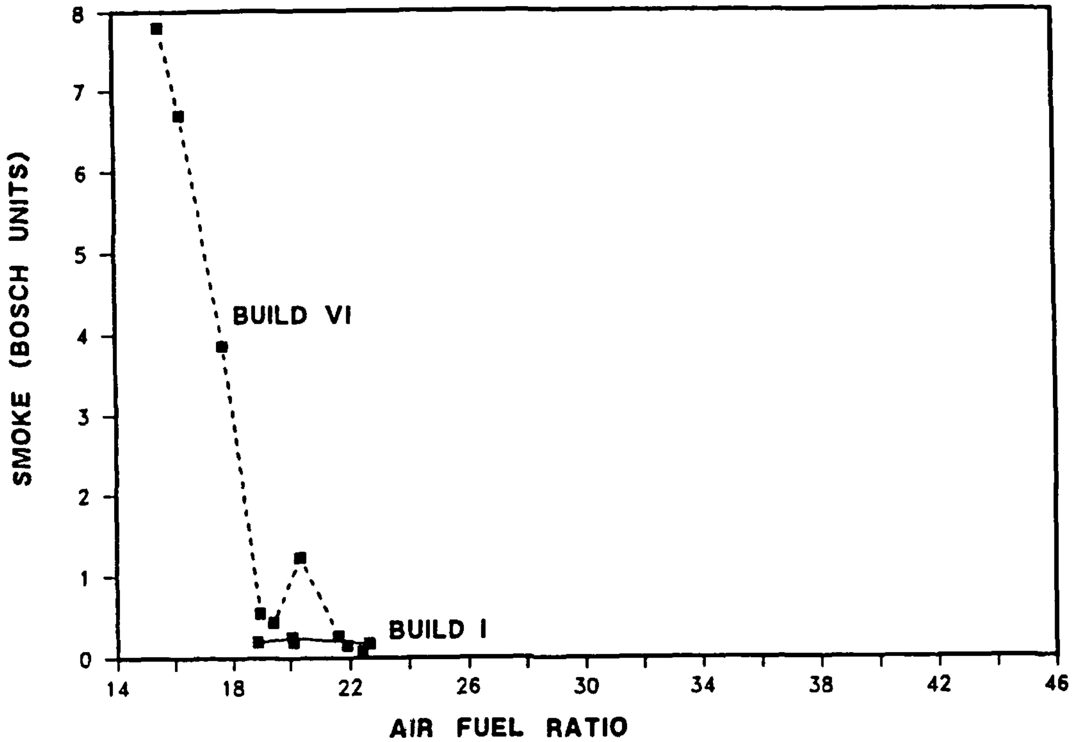

Figure 5.8.3-6 Smoke vs. A/f, Build I and Build VI

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Figure 5.8.4-1. Failed Head - Cracked

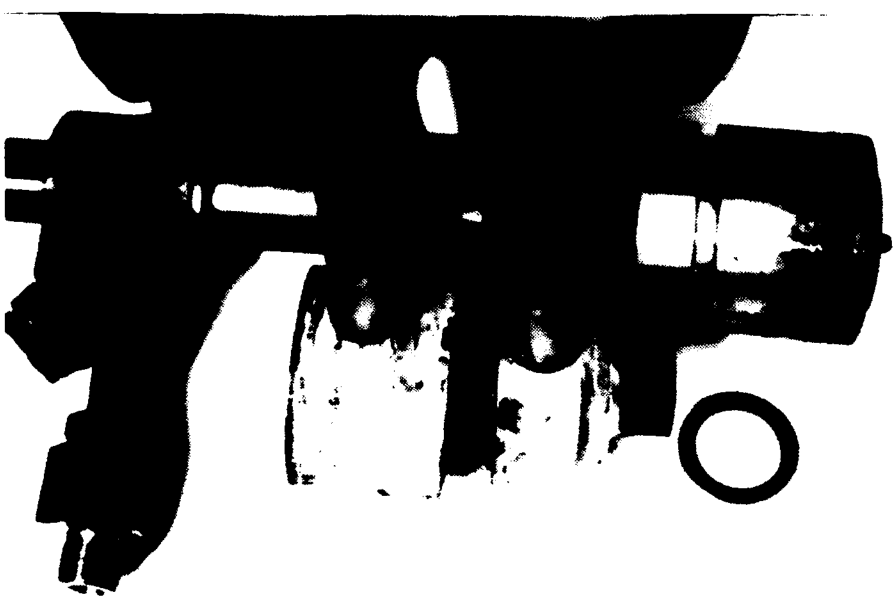

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Figure 5.8.4-2. Injector and Three Piece PCC

TICS chamber the compression ratio dropped to ₁2.0 and the chamber without the spacer to 15.6. Only the 84 cc chamber was run. The 34 cc chamber was not tested. Figure 5.8.4-3 shows the regime wherein this build was tested which shows high power operation at stoichiometric mixtures (180 psi BMEP an 16.5 A/F). Figure 5.8.4-4 and Figure 5.8.4-5 plot fuel consumption versus BMEP and A/F, respectively. The best fuel economy that this build achieved was 13 percent worse than the baseline Point 10 with a large percentage attributable to the reduction in compression ratio from 16.5 to 12.0 or 4.5 ratios. Figure 5.8.4-6 shows the that the smoke performance of this build was fairly good with very few points registering visible smoke and a smoke level of 0.8 achieved at an A/F ratio of 16.5.

5.8.5. Build VIIIA. Build VIII was an attempt to improve the performance by increasing the compression ratio and retaining the 84 cc TICS chamber. For this build a special higher compression ratio piston bowl was fabricated without valve pockets (Figure 5.8.5-1) and the cylinder head was modified so that the valves were recessed flush into the head. With these modifications the compression ratio was increased to 13.2. Figure 5.8.5-2 shows that this build was run primarily at A/F ratios between 16 and 18 and reduced power as compared to the baseline engine. Figure 5.8.5-3 shows that the fuel consumption of this build is worse than the baseline but that it is approaching Point 10. An extrapolation of the Build VIII test data would cross through Point 10. Figure 5.8.5-4 shows fuel consumption versus air fuel ratio. Comparing this data to Build VII shows that Build VIII caused the fuel economy to worsen. The smoke performance is shown as Figure 5.8.5-5 and shows that an A/F of 18:1 is needed to achieve non-visible smoke.

5.8.6. Build VII E & F. Following the Build VIII testing the engine was converted back into the Build VII configuration except that an insulating coating was added to the cylinder head face (a standard uncoated head was used for the first Build VII tests due to unavailability of a coated head). Figure 5.8.6-1 adds E & F builds to the previous Build VII data. This latest test was run at approximately constant A/F and load with various injection timings and injector nozzle areas. Figures 5.8.6-2 and 5.8.6-3 show that the fuel economy did not improve. However, Figure 5.8.6-4 shows that this build met the smoke target.

5.8.7. Build IX, X & XI. Three final builds of the engine were tested to determine the effect of using the AMBAC fuel pump and the BOSCH nozzle instead of the equivalent Caterpillar components. Build IX used the AMBAC fuel pump and the stock Caterpillar nozzle and precombustion chamber. The test was run with variable A/F and constant fuel flow. Build X used the stock Caterpillar nozzle, prechamber and fuel pump and was run in the same manner. Build XI used the stock Caterpillar fuel pump but with the BOSCH injector and the 84 cc air-gap insulated TICS chamber. The piston used for these tests was coated with a thermal barrier coating and the compression ratio of the engine with the

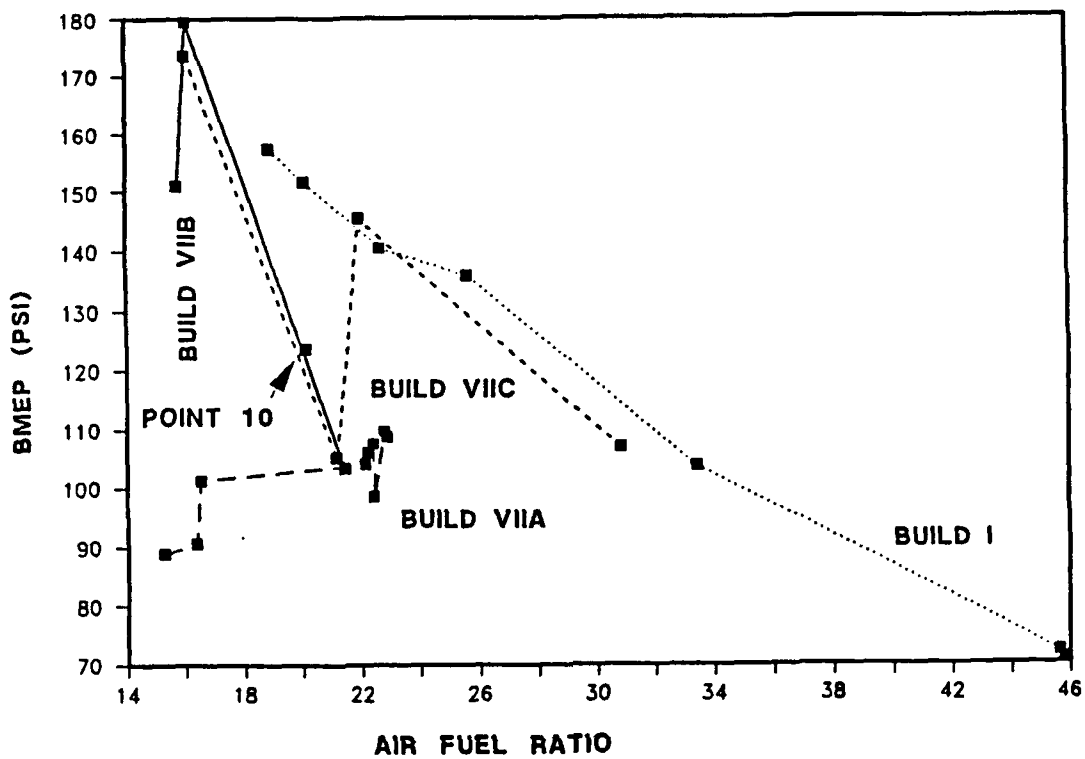

Figure 5.8.4-3 BMEP vs. A/F, Build I and Build VIIA, VIIB, and VIIC

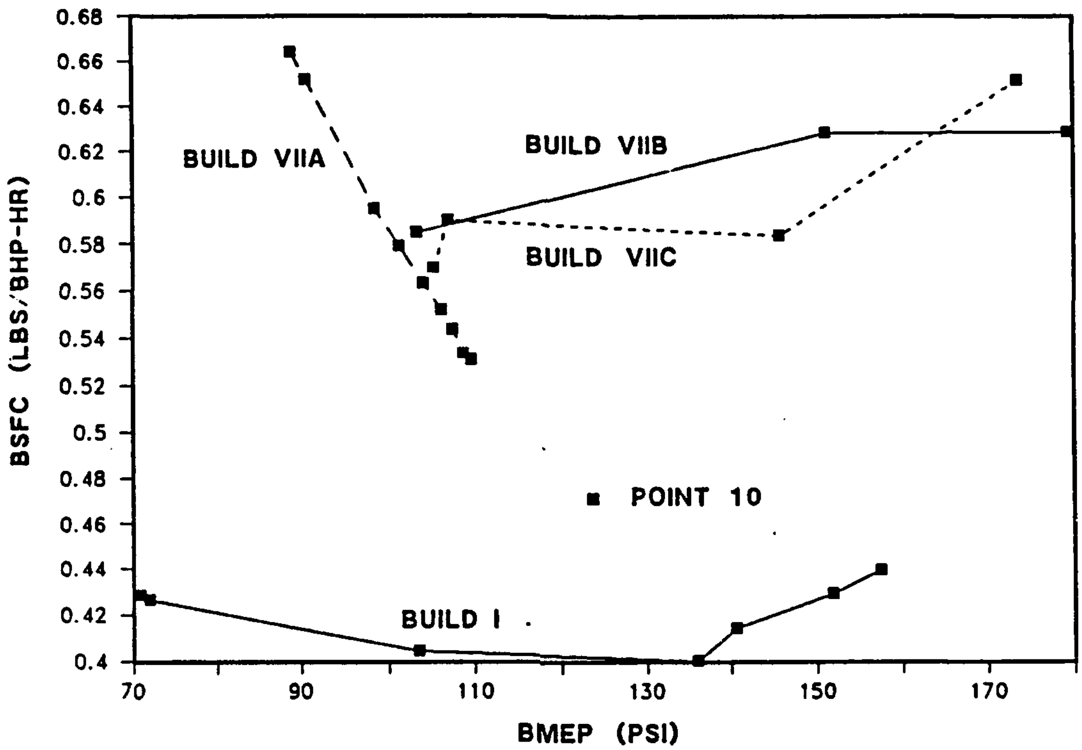

Figure 5.8.4-4 BSFC vs. BMEP, Build I and Build VIIA, VIIB, and VIIC

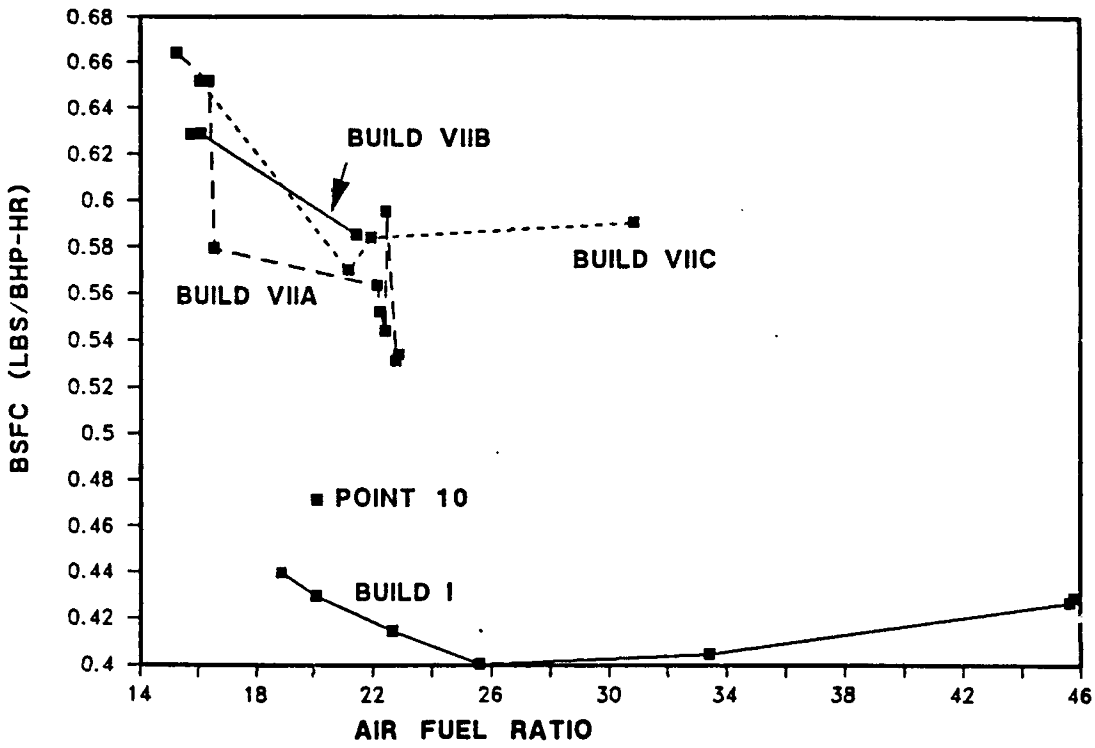

Figure 5.8.4-5 BSFC vs. A/F, Build I and Build VIIA, VIIB and VIIC

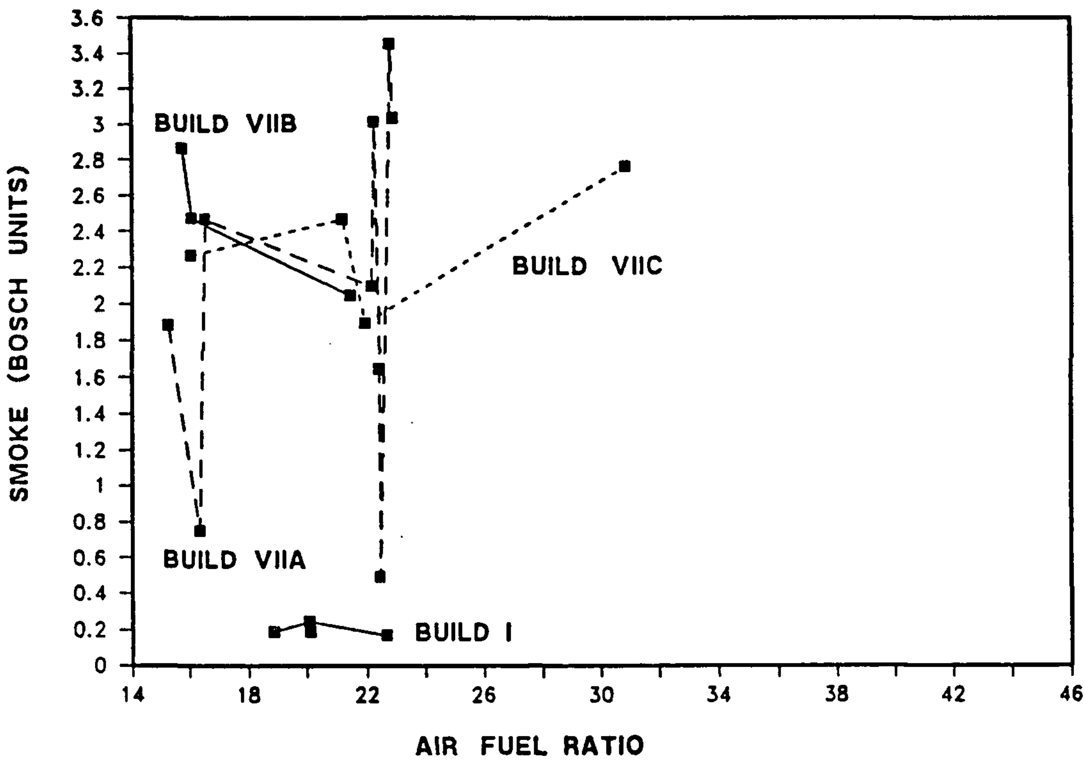

Figure 5.8.4-6 Smoke vs. A/F, Build I and Build VIIA, VIIB and VIIC

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Figure 5.8.5-1. High Compression Piston

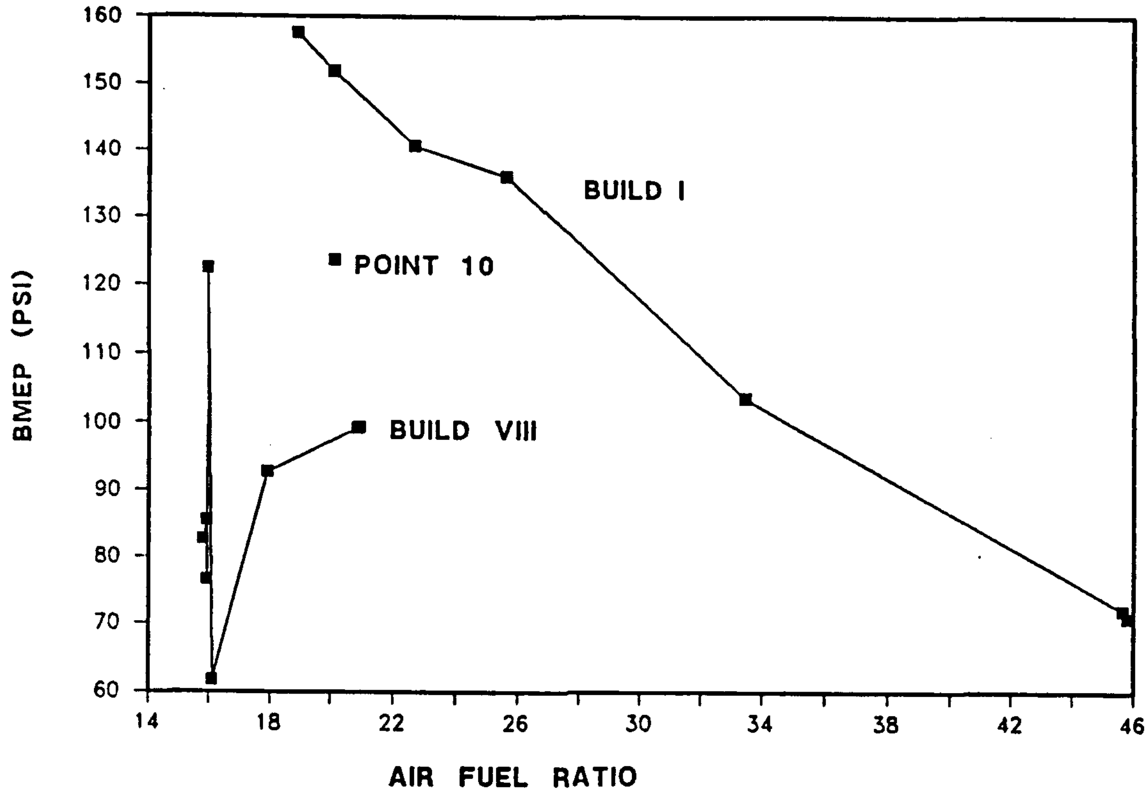

Figure 5.8.5-2 BMEP vs. A/F, Build I and Build VIII

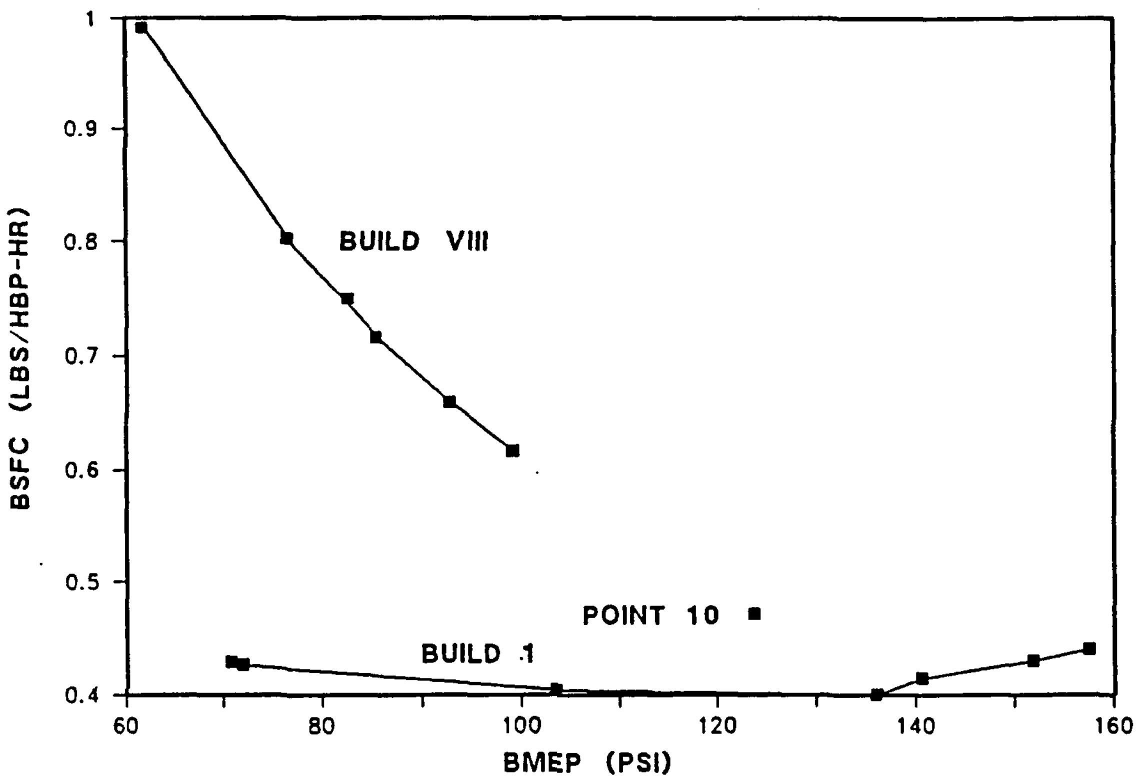

Figure 5.8.5-3 BSFC vs. BMEP, Build I and Build VIII

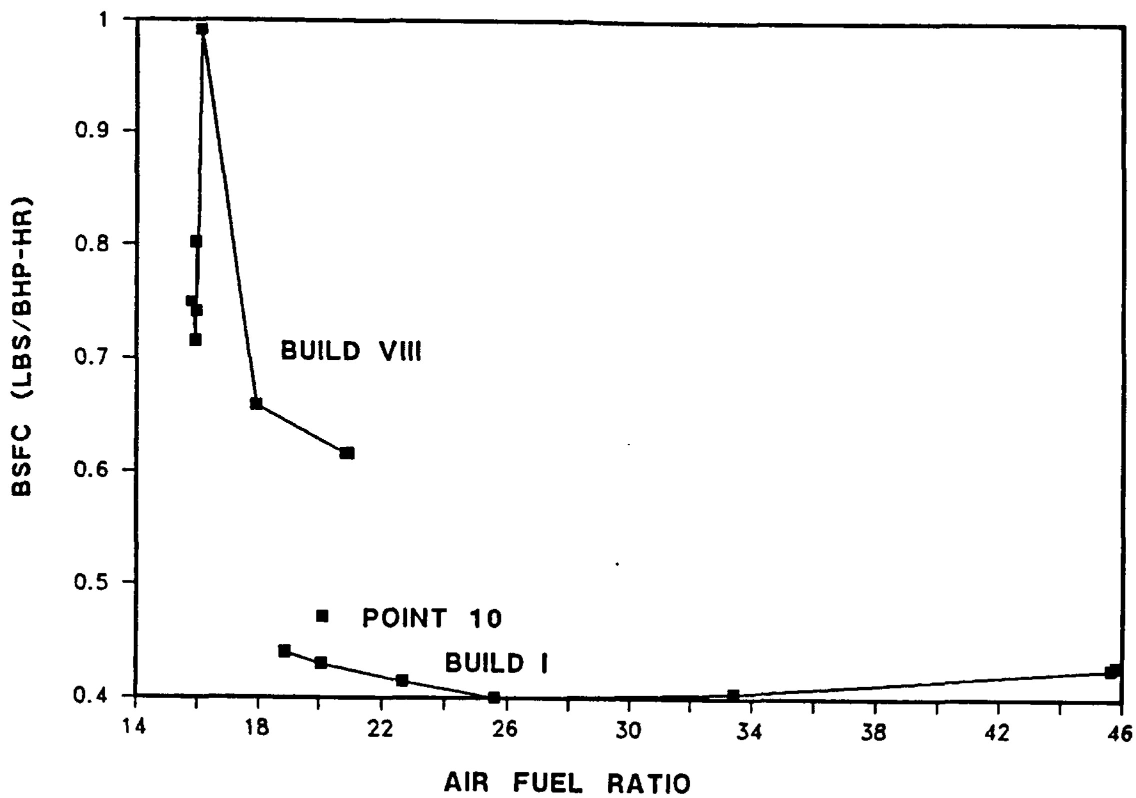

Figure 5.8.5-4 BSFC vs. A/F, Build I and Build VIII

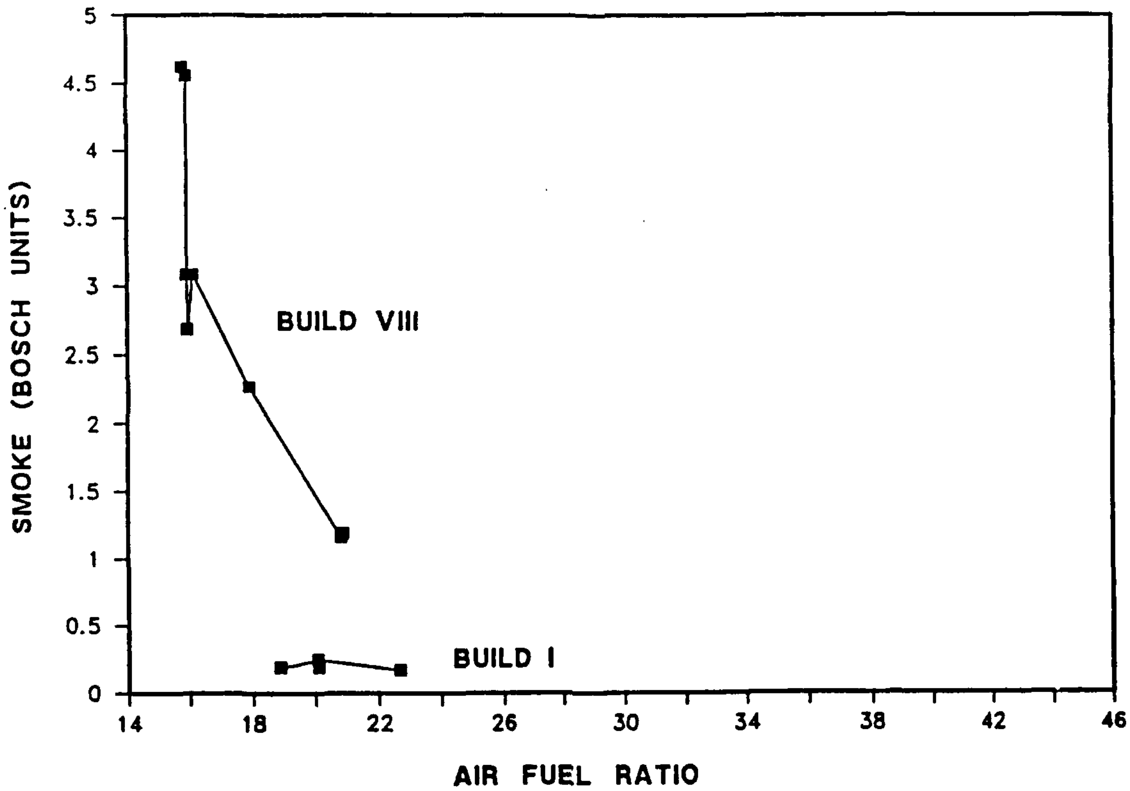

Figure 5.8.5-5 Smoke vs. A/F, Build I and Build VIII

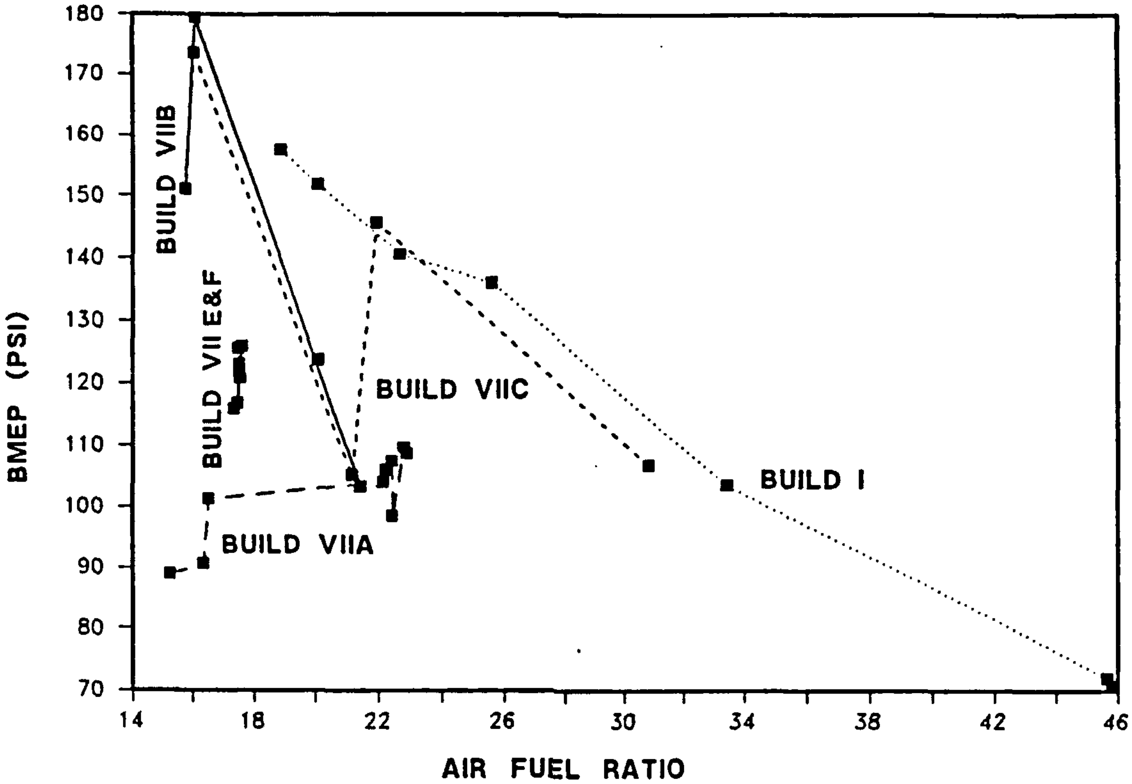

Figure 5.8.6-1 BMEP vs. A/F, Build I and Build VIIA, B, C, E and F

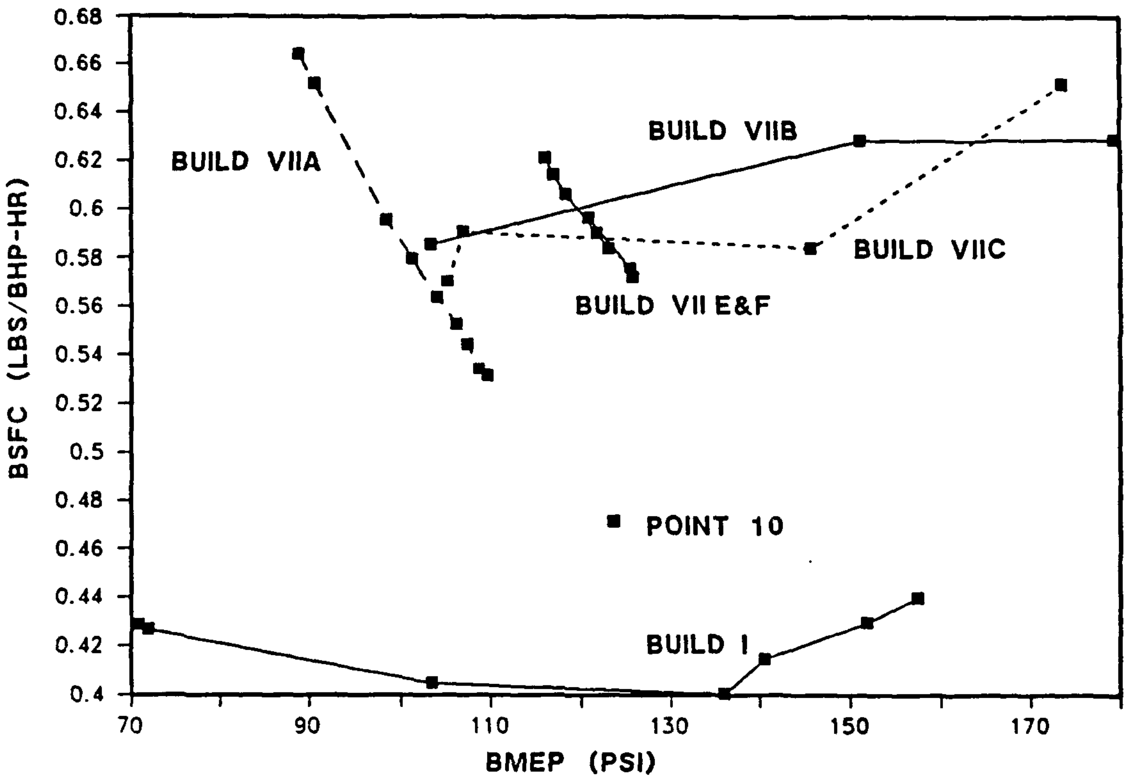

Figure 5.8.6-2 BSFC vs. BMEP, Build I and Build VIIA, B, C, E and F

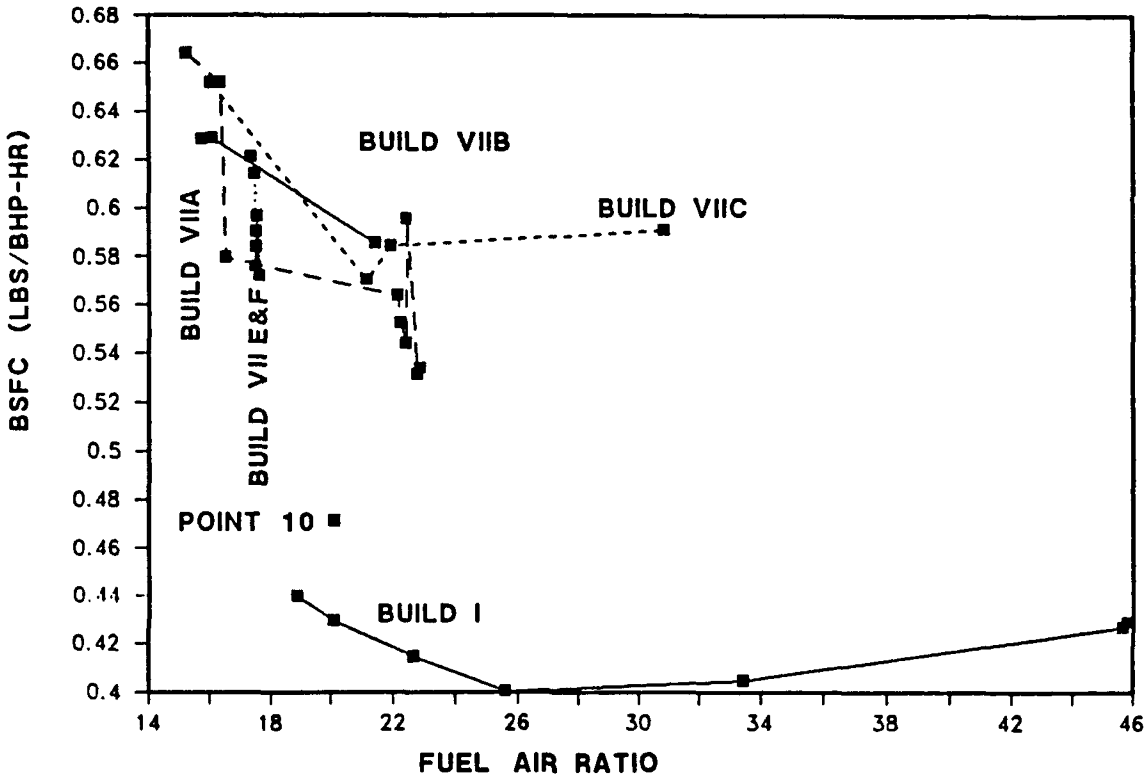

Figure 5.8.6-3 BSFC vs. A/F, Build I and Build VIIA, B, C, E and F

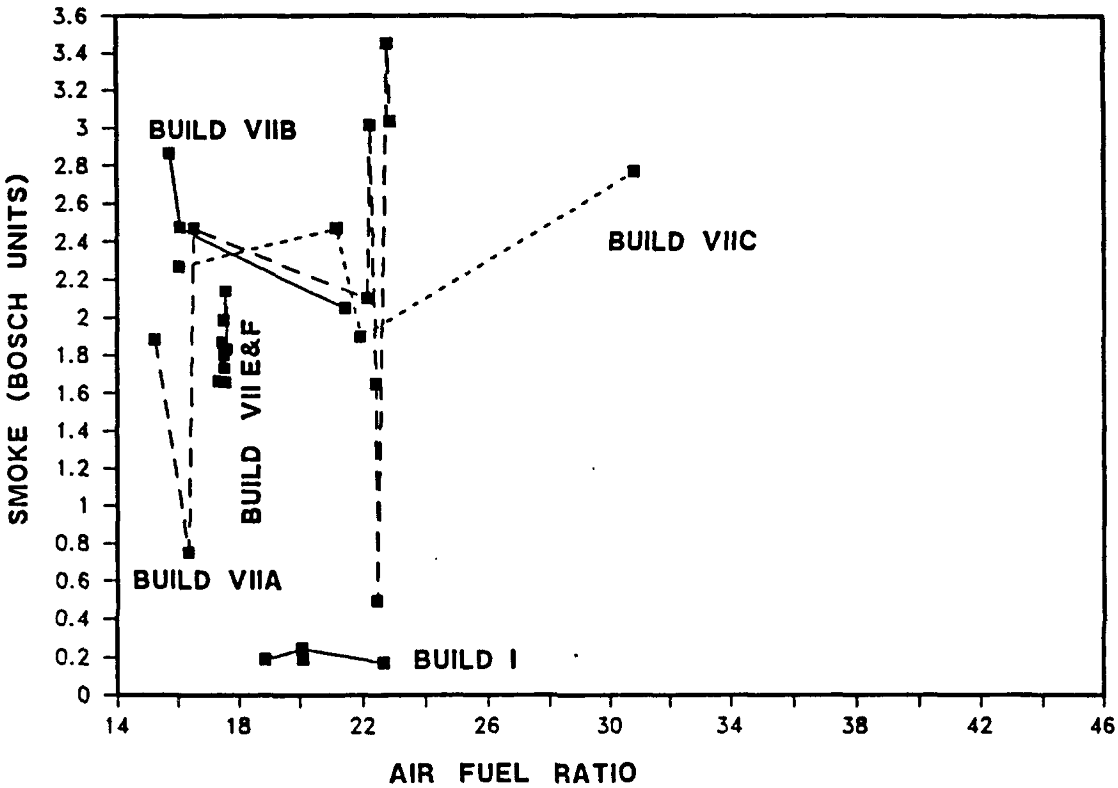

Figure 5.8.6-4 Smoke vs. A/F, Build I and Build VIIA, B, C, E and F

standard Caterpillar precombustion chamber was 14.9 and was 12.0 with the 84 cc TICS chamber.

Figure 5.8.7-1 shows the points where this data was taken. Within test limitations the tests were run at higher loads and richer A/F ratios than the baseline test Point 10. Figure 5.8.7-2 shows that the fuel consumption versus BMEP for all three of these builds falls on a single line which can be extrapolated to show better fuel economy than the standard build at high loads. Figure 5.8.7-3 and Figure 5.8.7-4 show that the build with the stock fuel pump and injector (Build X) performed better that the engine with the special fuel pump and injector and gave the best smoke levels. This final test confirmed our suspicions that the fuel system configuration, which was used for the stoichiometric combustion development, was not well optimized and that with optimization the engine performance would be significantly improved. It should be noted that the stock Caterpillar components were not used because of the need for variable injection timing and because the stock nozzle can not be used on an uncooled precombustion chamber without serious failures.

5.8.8. Engine Testing Summary. All of the testing results have been examined in detail and as part of the total picture. Figure 5.8.8-1 is a three dimensional plot of brake specific fuel consumption as a function of air fuel ratio and brake mean effective pressure. Superimposed on the plot is the result of a three dimensional regression analysis of a simple plane which best describes the test data. For ease is locating particular points, the reflection of the point is shown is the x-y plane. Each test point is shown as a balloon which is attached to the regression plane by a string. Looking at the point at the extreme right edge of the plot it is easy to see that the point is above the regression plane, or has a higher fuel consumption than the plane represents. Examining the slope of the plane it is observed that fuel consumption improves by either increasing the BMEP or increasing the F/A ratio. Making and presenting this plot, and the following three figures comparing all of the test data, one must somehow take into account the effect of other variables such as compression ratio, injection system optimization, intake air temperature, injection timing, and corrections for parasitic differences (such as cooling power requirement differences between a cooled and uncooled engine). Unfortunately, while these corrections could be made, it is likely that the significance and believability of the data would probably be reduced to an unacceptable level. Therefore, the data is presented without any of these corrections—all of which would improve the relative performance of the stoichiometric diesel engine.

Figure 5.8.8-2 and Figure 5.8.8-3 are plots of brake specific fuel consumption as a function of brake mean effective pressure and of air fuel ratio, respectively, for the baseline data and four stoichiometric builds. Examining these two plots the plus sign symbol shows the baseline point 10 performance. All of the other engine builds are identified with different symbols. From these graphs it can be

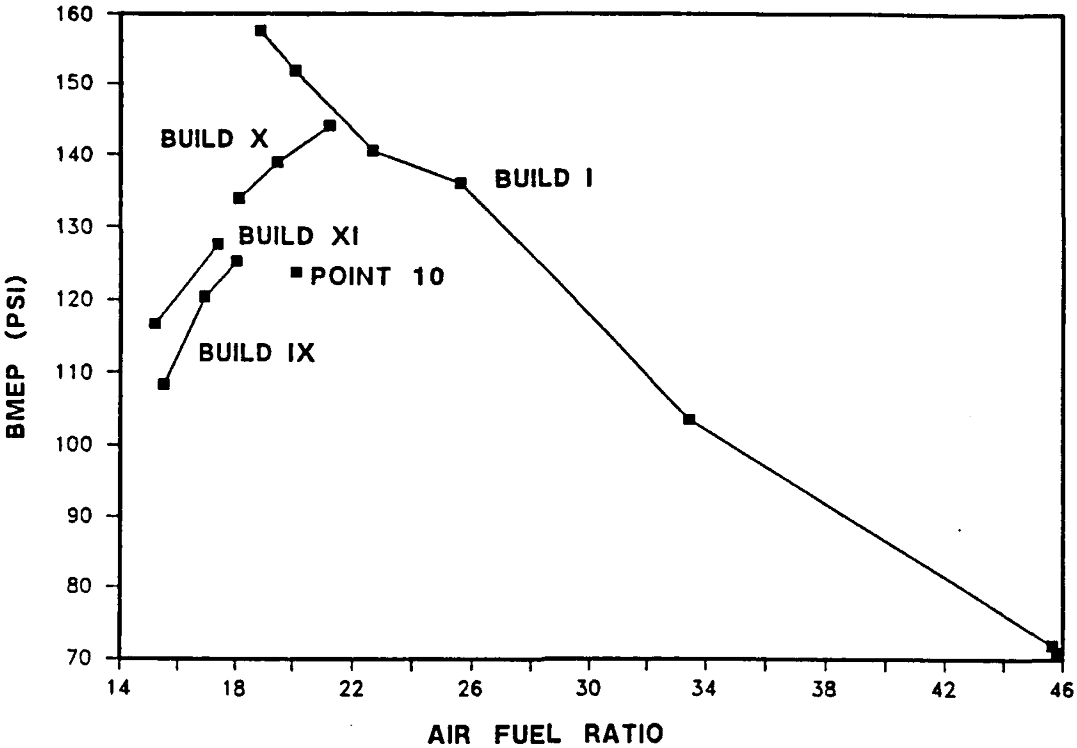

Figure 5.8.7-1 BMEP vs. A/F, Build I and Build IX, X and XI

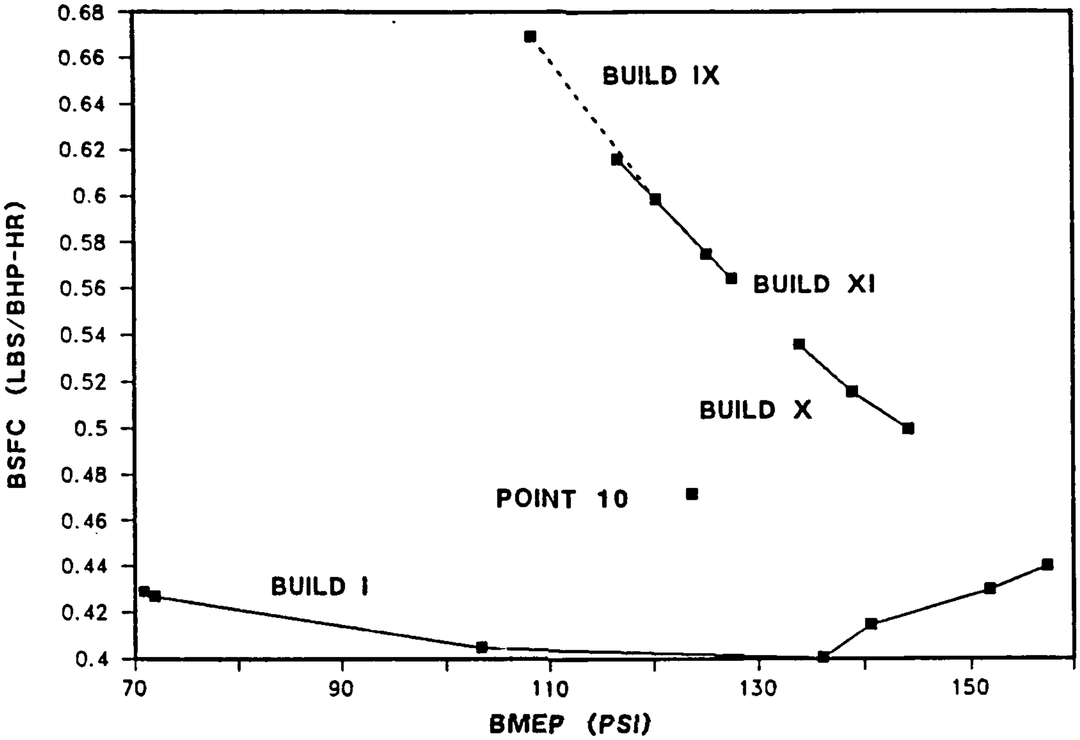

Figure 5.8.7-2 BSFC vs. BMEP, Build I and Build IX, X and XI

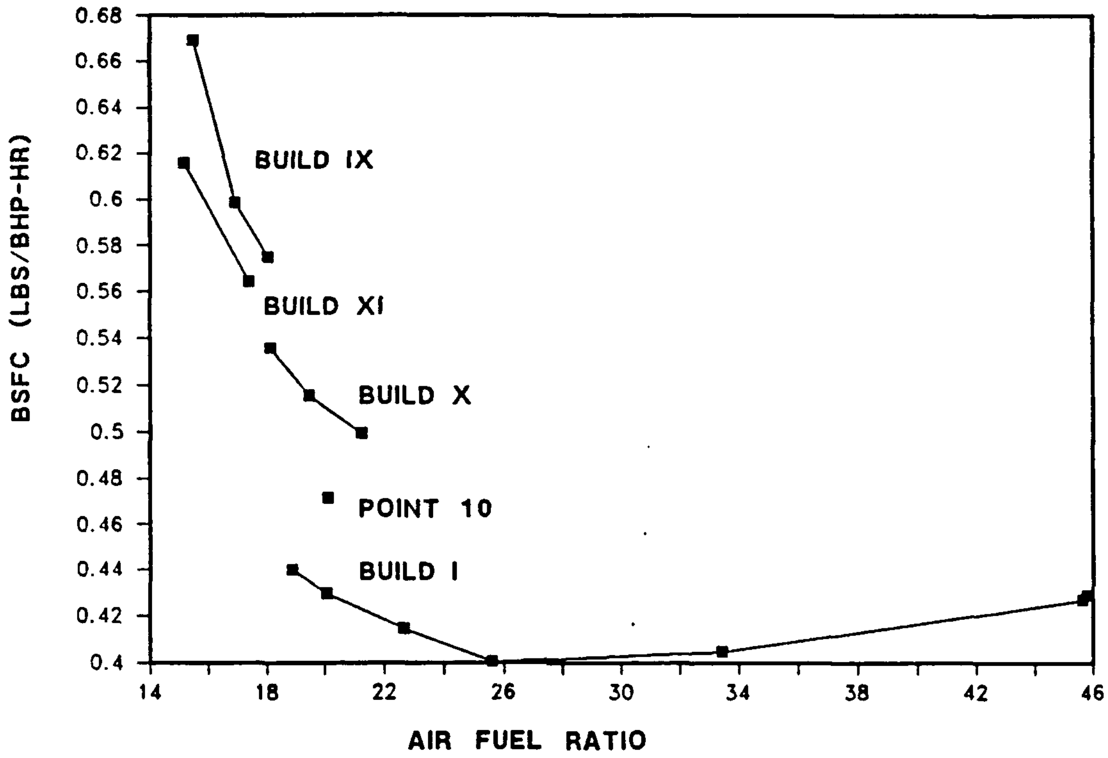

Figure 5.3.7-3 BSFC vs. A/F, Build I and Build IX, X and XI

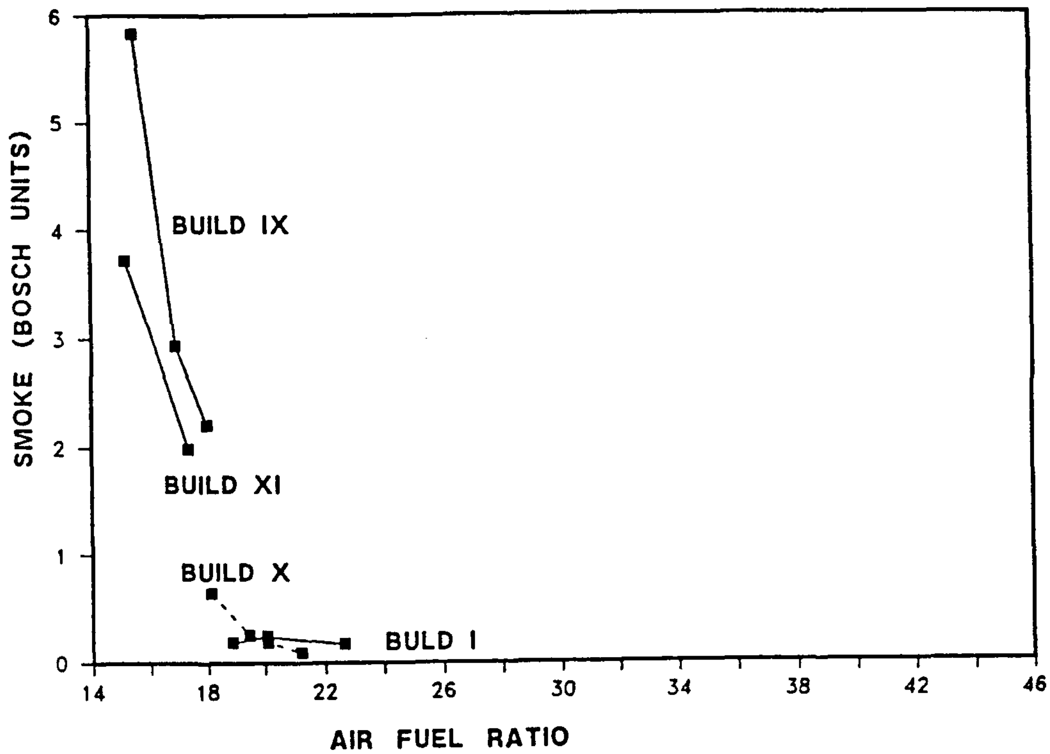

Figure 5.8.7-4 Smoke Vs. A/F, Build I and Build IX, X and XI

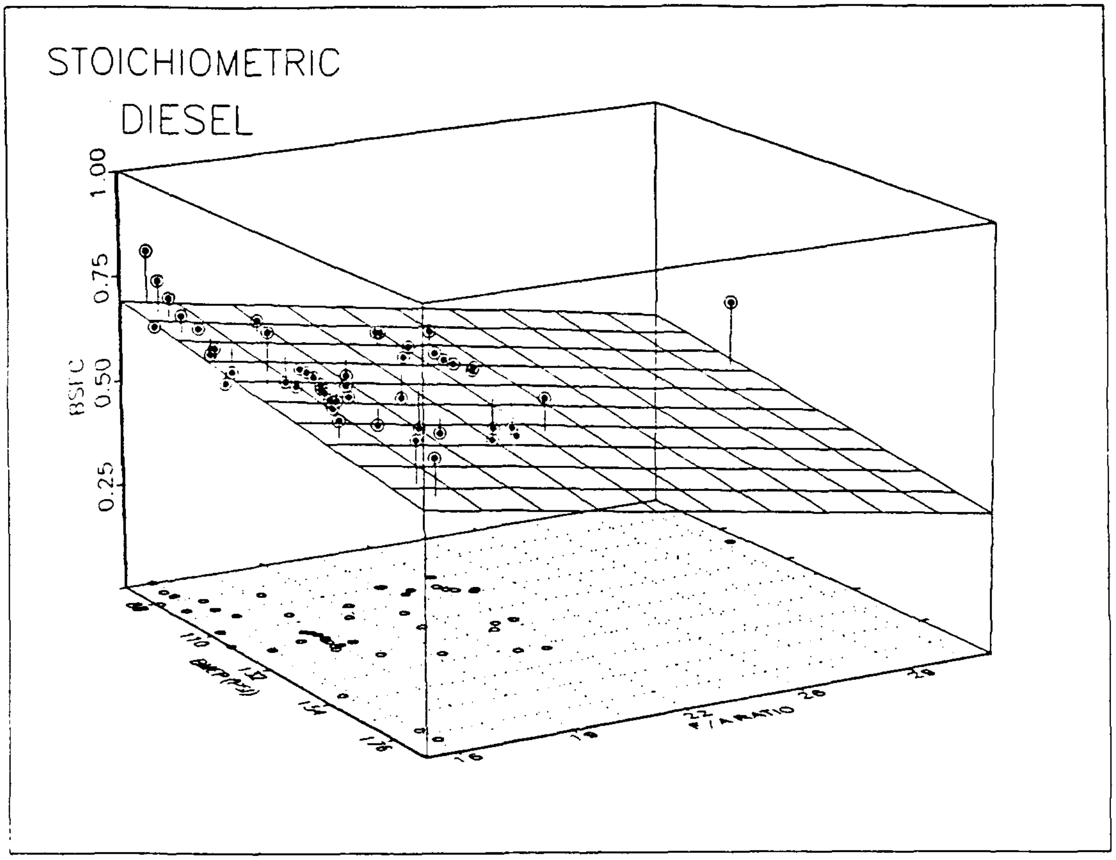

Figure 5.8.8-1. Three Dimensional Plot of BSFC vs. A/F and BMEP

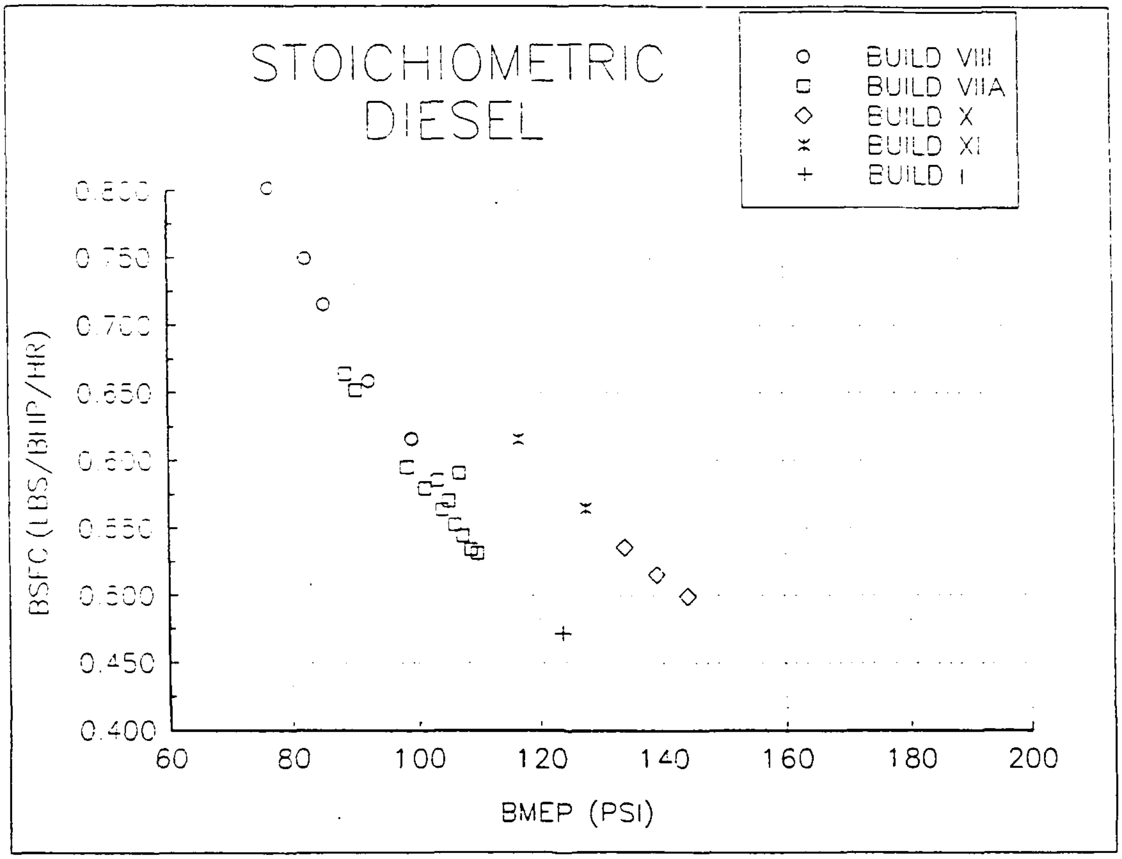

Figure 5.8.8-2. BSFC vs. BMEP and A/F

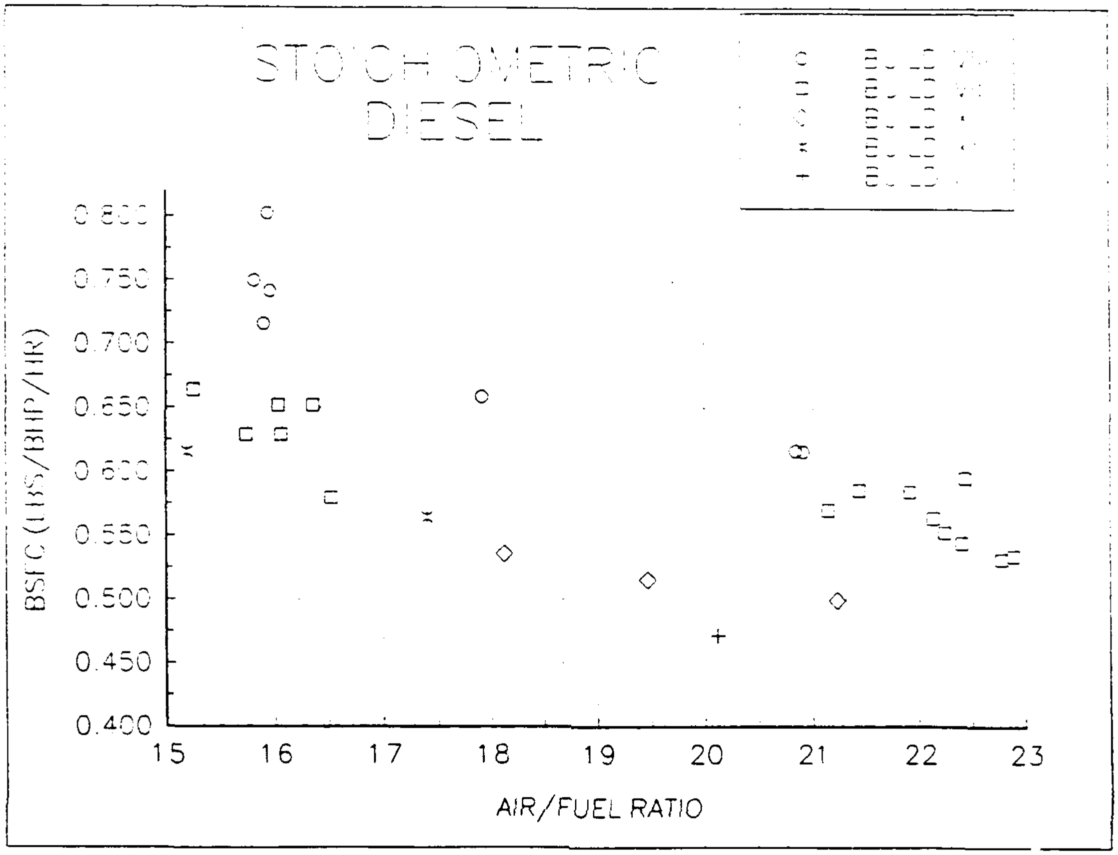

Figure 5.8.8-3 BSFC Vs. BMEP and AIF

concluded that Builds VII and X have the best performance and show the smallest degradation in fuel consumption as the mixture approaches stoichiometric. Three test points were taken during Build VIIC wherein the peak pressure was held constant over a wide range of air fuel ratio by increasing the power output at the richer mixtures. These test points 48, 49 and 50 are plotted as Figure 5.8.8-4. As the fuel air ratio was decreased from about 31 to 16 the peak cylinder pressure was held constant at 1500 psi and the BMEP increased from 107 to 174 psi, a 63 percent increase. The brake specific fuel consumption increased by only 10 percent over this extreme range. As the data shows the smoke was actually lower at the stoichiometric condition, at a level of about 2.3 bosch units.

5.8.8.1. Durability Considerations. While the purpose of this program was intended to be strictly engine performance oriented, it is worthwhile to discuss the engine durability implications as indicated by problems encountered during the test program. The problems were all the result of the engine running at elevated temperatures. Exhaust temperatures over 1700 $^{\circ}$F were routine and were occasionally over 1800 $^{\circ}$F Also internal component insulation and testing without component cooling further increased component temperatures. The types of failures were of three types: lubrication breakdown, coating failures, and structural failures. The only instances of structural failures were the local yielding of the TICS bowl in the piston and the multiple failures of the cylinder head due to low cycle compression yielding and subsequent cracking which were discussed earlier. Two examples of lubrication breakdown are shown as Figures 5.8.8.1-1 and 5.8.8.1-2 showing first a stuck top ring and second a scuffed piston skirt. There were multiple failures of these types which were encountered whenever the top ring reversal temperature exceeded about 575 $^{\circ}$F which is the maximum operating temperature of the lubricant. Figure 5.8.8.1-3 and Figure 5.8.8.1-4 are photographs of failed coatings on intake and exhaust valves, respectively, and Figure 5.8.8.1-5 shows failure of the coating on a piston crown.

5.9 Task VII - Data Transfer - MultiCylinder

The last technical task in the program was to utilize the single cylinder engine test data to predict the performance of a multicylinder stoichiometric diesel engine. Referring back to the test results and particularly Figures 5.8.7-3 and 5.8.8-3, it was shown that operating at near stoichiometric conditions (18 to 1 air/fuel ratio) that the specific fuel consumption of the engine is degraded approximately ten percent from optimum. It was also shown that at constant peak cylinder pressure the output of a diesel engine can be increased by 63 percent by reducing the air/fuel ratio from thirty one (31) to sixteen (16) and maintain acceptable smoke levels.

Table 5.9-1 (which was also used as Table 3.0-1) tabulates the predicted performance of a Cummins V903 engine in both standard and turbocompound configurations as well as stoichiometric ratings. All of the engine

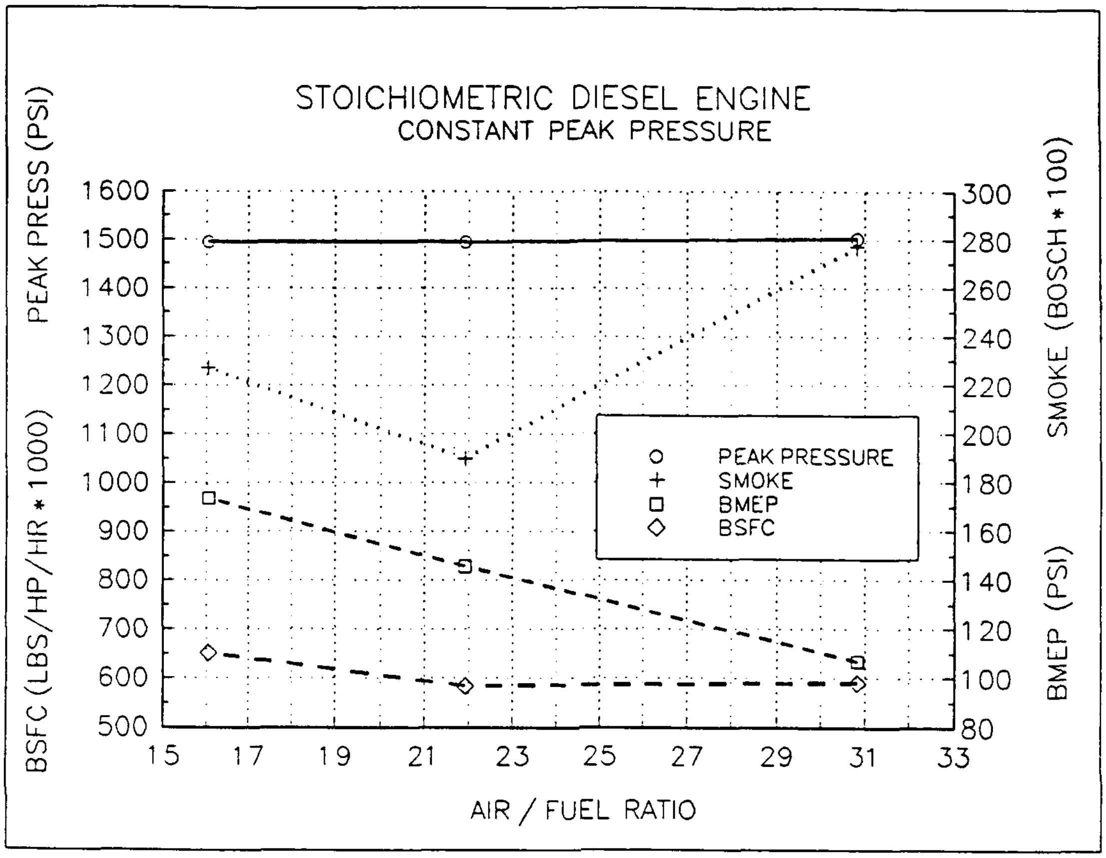

Figure 5.8.8-4 Test Points 48, 49, and 50

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Figure 5.8.8.1-1 Stuck Top Ring

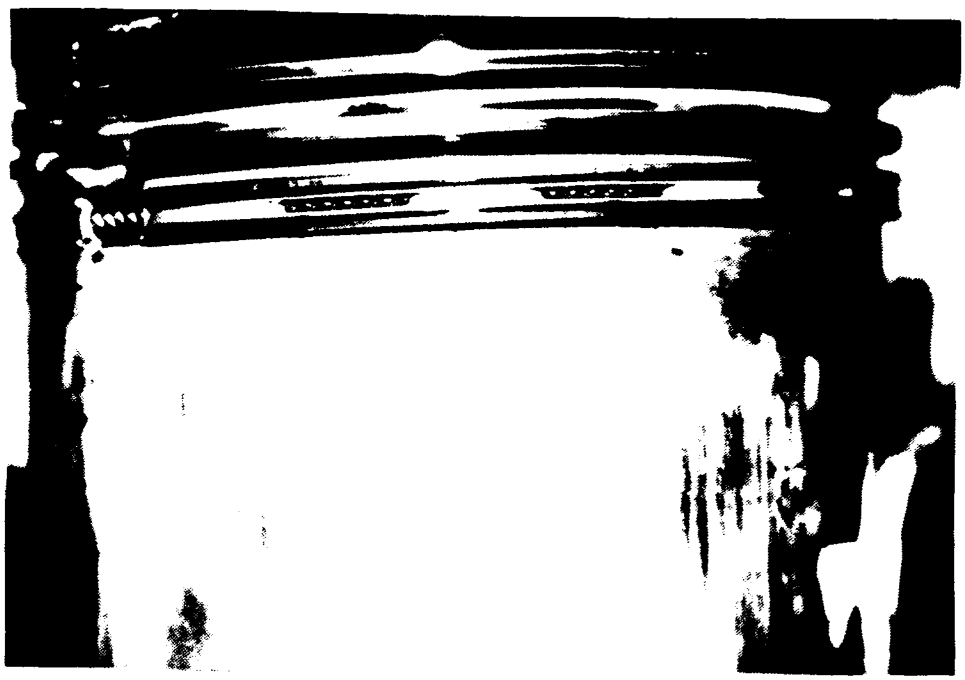

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Figure 5.8.8.1-2. Scuffed Piston

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Figure 5.8.8.1-3. Failed Intake Coating and Good Head

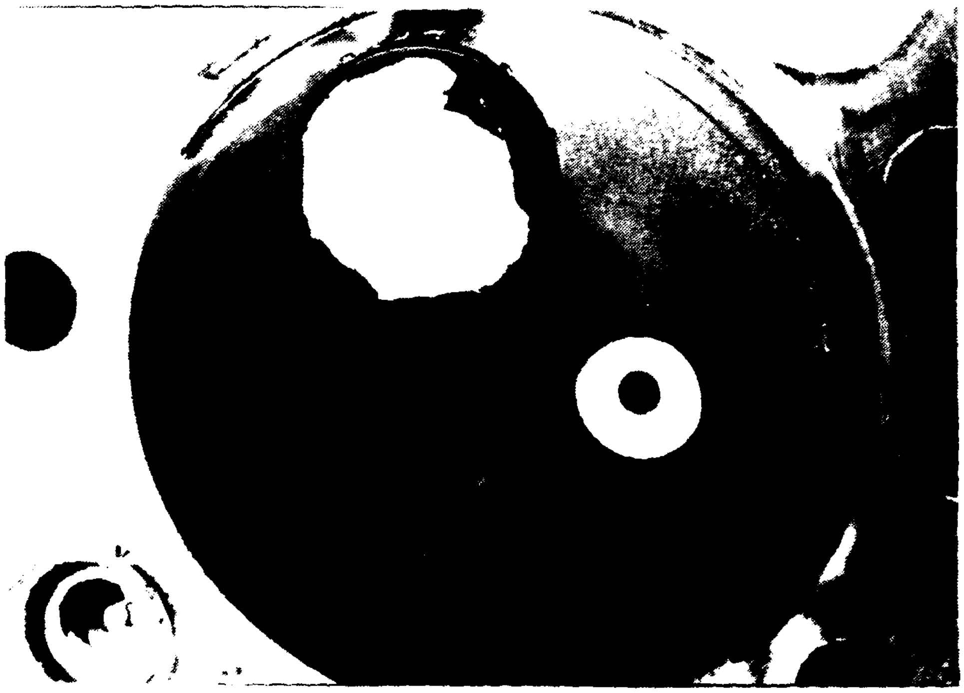

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Figure 5.8.8.1-4. Failed Exhaust and Good Head

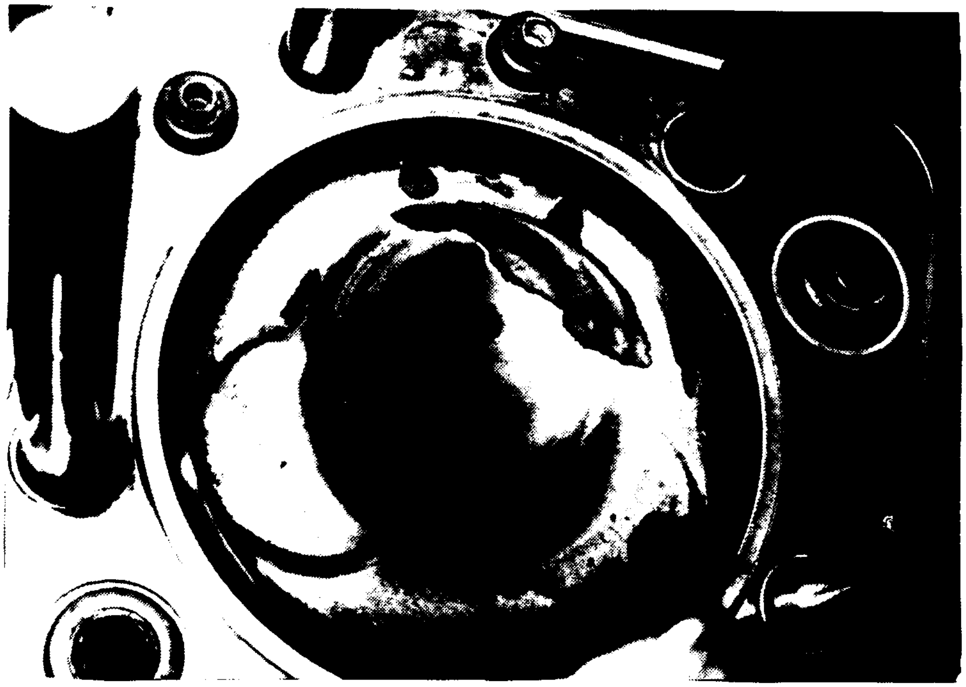

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Figure 5.8.8.1-5. Failed Piston Coating

Table 5.9-1 Stoichiometric Engine Comparison

STOICHIOMETRIC ENGINE COMPARISON

CHARACTERISTIC	TURBOCHARGED STANDARD	TURBOCHARGED STOICH.	TURBOCOMPOUND STANDARD	TURBOCOMPOUND STOICH.
AIR/FUEL RATIO	28	18	28	18
RATED BMEP (psi)	202	293	213	315
RATED IMEP (psi)	237	328	248	350
OUTPUT (BHP)	600	870	630	935.4
ISFC (lbs./IHP/hr.)	0.298	0.328	0.286	0.307
BSFC (lbs./HP/hr.)	0.350	0.367	0.333	0.341
FUEL FLOW (lb/hr.)	210	319	210	319
AIR FLOW (lb/hr.)	5880	5747	5880	5730

THE FOLLOWING CHARACTERISTICS ARE CONSTANT

DISPLACEMENT (cubic inches)	903
PEAK CYLINDER PRESSURE (psi)	2,000
RATED SPEED (rpm)	2,600
NUMBER OF CYLINDERS	8
BORE (inches)	5.50
STROKE (inches)	4.75

ratings are made for a fixed engine speed of 2600 RPM and a fixed peak pressure of 2000 psi. The first column shows the performance of the current 600 horsepower engine (assuming an air/fuel ratio of 28 to 1). Going down the first column the rated BMEP is 202 psi. Assuming (for each engine) a friction mep (fmep) level of 35 psi, the imep is 237 psi. Assuming a rated bsfc of 0.350 lbs/bhp-hr the isfc then calculates to be 0.298 lbs/bhp-hr. A fuel flow of 210 lbs/hr and an air flow of 5880 lbs/hr are then calculated from the horsepower, bsfc and A/F ratio. Moving to the second column assuming an A/F ratio of 18 for the stoichiometric engine rating and an increase in the isfc of 10 percent the following conditions are calculated. Based upon the test results from points 48,49 and 50 the BMEP will increase by a minimum of 45 percent for this change of F/A ratio with no increase in peak pressure. A constant friction mep (fmep) of 35 psi added to this value yields an imep of 328 psi. The brake output of the engine is now 870 horsepower. Based upon a degradation of isfc of 10 percent the new isfc is 0.328 lbs/bhp-hr which results in a fuel flow of 319 lbs/hr and a brake specific fuel consumption of 0.387 lbs/bhp-hr. The air flow is reduced to 5747 lbs/hr, which means that the stoichiometric rating of 870 horsepower can use the same intake air system and turbocharger/intercooler as the 600 horsepower engine.

The third column in Table 5.9-1 shows the performance of the standard engine with the addition of turbocompounding. A realistic estimate of the additional power attainable by using a power recovery turbine is five percent (5 %) of rated power or 30 horsepower. In order to determine the additional energy recoverable by turbocompounding as shown in column 4, it was necessary to determine how much additional energy was made available due to the reduction in A/F ratio as a result of the increase in exhaust temperature. Figure 5.9-1 is a log-log plot of the temperature rise (exhaust manifold temperature minus intake manifold temperature) across the engine for seven different engines as a function of A/F ratio. The seven engines are:

STOICH	-	Stoichiometric test results on the Caterpillar 1Y73 for builds VI through XI with cylinder head and liner cooling.
V903	-	Standard water cooled production Cummins V903 taken for a 350 horsepower rating development program.
5 TON	-	Data obtained by Adiabatics during the testing of the uncooled Cummins NT855 from the U.S. Army Adiabatic 5 ton truck.
AIPS	-	Test results from development and performance testing of the uncooled AVL/AIPS single cylinder engine at Adiabatics.
NTA	-	Data from a standard water cooled Cummins NTA 855 engine.
NHSCE	-	Data from an un-cooled single cylinder Cummins NTA 855 engine, data taken at Cummins.
CAT	-	Data from a standard water-cooled Caterpillar 1Y73 single cylinder oil test engine.

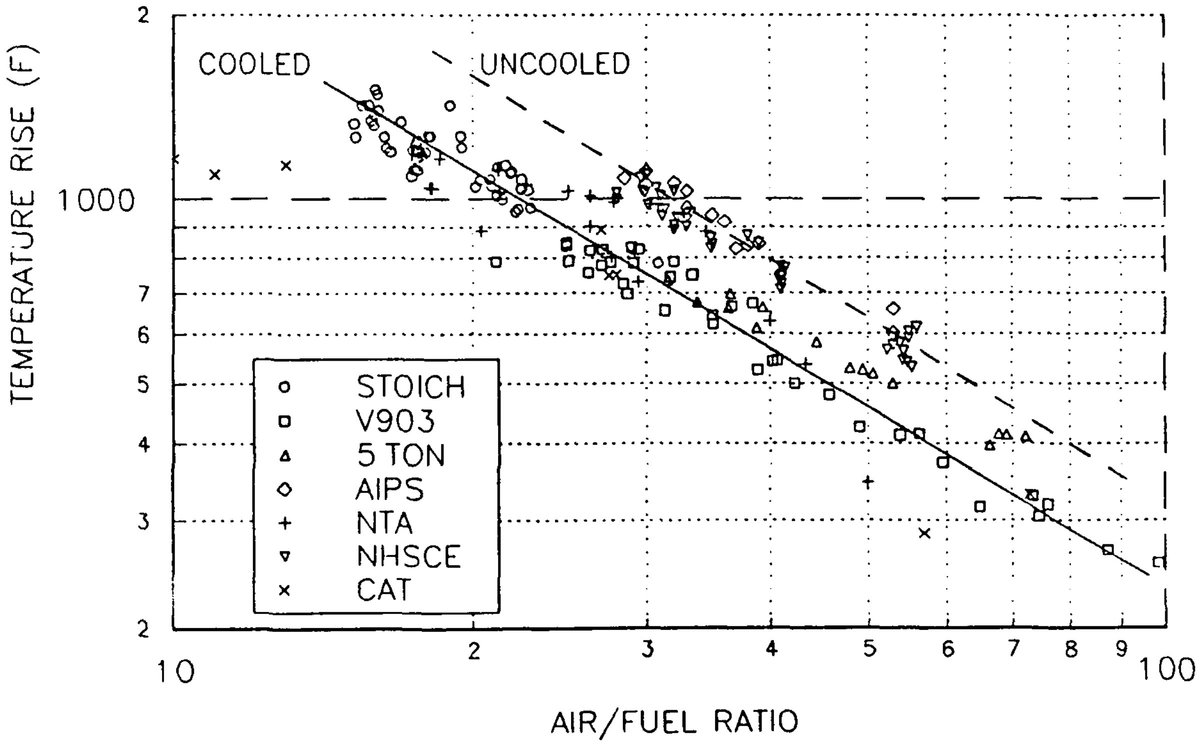

Figure 5.9-1 Engine Temperature Rise Exhaust Minus Intake

A best fit (linear regression analysis of the data in the log-log regime) grouping the cooled and uncooled engines separately shows that the low heat rejection uncooled engines have a higher temperature rise at a given air fuel ratio than cooled engines. Figure 5.9-2 shows the same data with best bit curves for each individual engine with the data and curve for the stoichiometric testing being the solid bold line. This is obvious from the graph that the stoichiometric data falls in the center of the data from all of the other engines and has a slightly lower slope than the other engines (meaning that the temperature rise increases less as the air fuel ratio decreases.) Figure 5.9-3 shows only the stoichiometric data and the equation from the regression analysis. Using this equation the temperature rise is 865 ^{o}F for the engine at an air fuel ratio of 28 and 1,280 ^{o}F at 18:1. Table 5.9-2 shows the results of an analysis comparing the stoichiometric and standard turbocompound engines. Using an intake air temperature of 200^{o}F, the available energy in the exhaust rises from 11,858 to 14,420 Btu/min when the engine is made stoichiometric. Using an engine cycle simulation with a compressor efficiency of 75 percent, it is predicted that the compressor power requirements for the stoichiometric engine will drop from 118 to 115 horsepower. Assuming that the stoichiometric engine can recover the same percentage of total available exhaust energy as the standard engine, it is estimated that the power recovery will increase from 30 to 65.4 horsepower and that the brake power output of the turbocompound stoichiometric V903 engine will be 935.4 horsepower. As shown in Table 5.9-1, the specific fuel consumption for this engine will be 0.341 which is lower than the existing 600 horsepower rating.

5.10 Task VIII - Recommendation

Based upon the results of this program, it is recognized that the specific power output (based upon weight and/or volume) of diesel engines can be significantly improved by decreasing the air fuel ratio (stoichiometric operation.) It is recommended that the stoichiometric concept, with turbocompounding, be applied to the existing Cummins V903 engine to increase the power output from 600 to 935 horsepower without increasing the engines peak cylinder pressure or requiring a new turbocharger or air handling system.

The detailed recommendations are listed in paragraph 4.0 Recommendations.

5.11 Task IX - Reporting

Per the contractual requirements, the program reporting consisted of monthly technical progress reports, biannual steering committee meetings and a final technical report. These items were successfully completed including four steering committee meetings. The contents of the steering committee meetings were documented by handouts, which included copies of all of the visual materials presented.

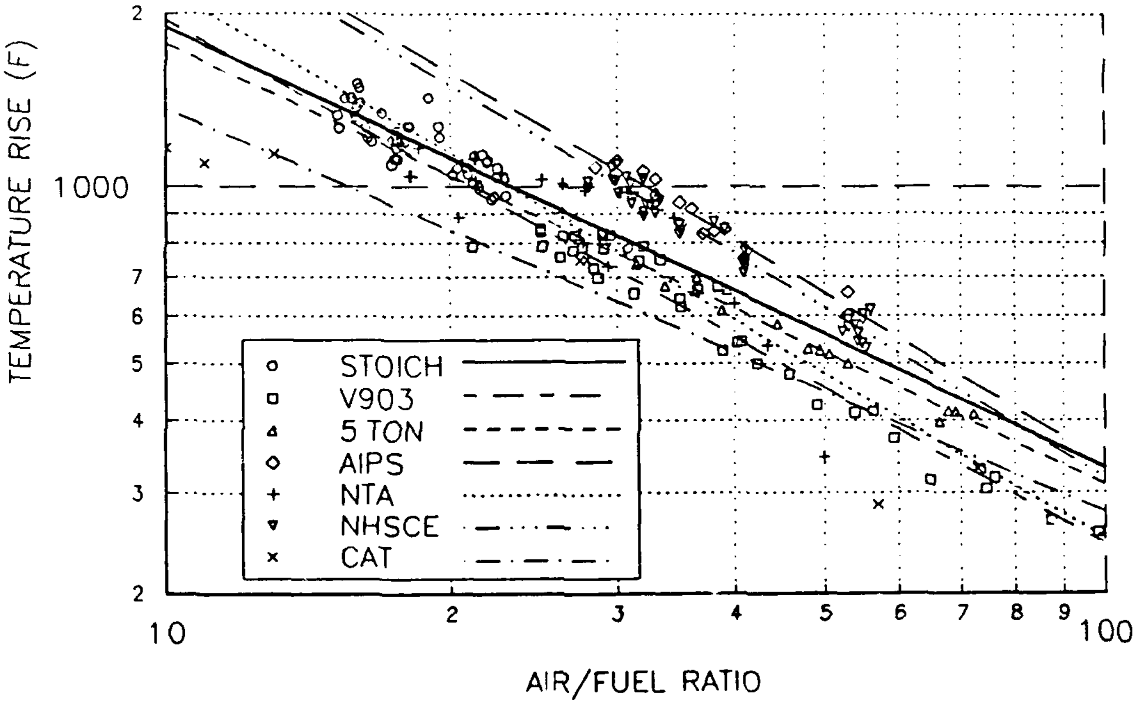

Figure 5.9-2 Engine Temperature Rise Exhaust Minus Intake

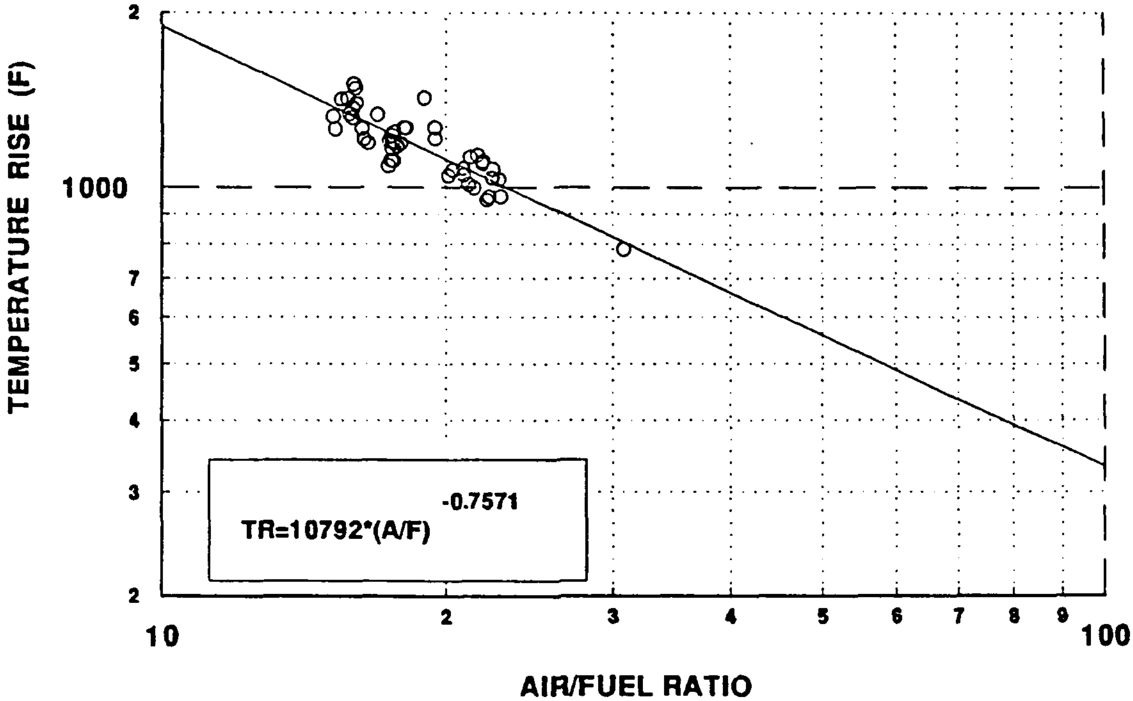

Figure 5.9-3 Stoichiometric Diesel

Table 5.9-2 Turbocompounding Analysis

TURBOCOMPOUNDING ANALYSIS

	STANDARD	STOICHMTRC.
AIR/FUEL RATIO	28	18
EXPANSION RATIO	4	4
EXHAUST TEMPERATURE (R)	1,525	1,870
AVAILABLE ENERGY (BTU/lb.)	121	151
AIRFLOW (lbs./HOUR)	5,880	5,730
AVAILABLE EXH. POWER (BTU/min.)	11,858	14,420
TOTAL TURBINE POWER (HP)	279	340
BASE ENGINE POWER (HP)	600	870
PERCENT RECOVERY	5.0	7.5
RECOVERY TURBINE (HP)	30	65.4 (B)
TOTAL ENGINE POWER (HP)	630.0	935.4
COMPRESSOR POWER (HP)	118	115 (A)

(A) STOICHIOMETRIC COMPRESSOR POWER $= \frac{5730}{5880} \times 118 = 115$

(B) STOICH. RECOVERY POWER $= \frac{(118 + 30)}{279} \times 340 - 115 = 64.5$

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4 Uyehara, O., "Effect of Burning Zone A/F, Fuel H/C on Soot Formation and Thermal Efficiency," SAE Technical Paper 800093, (1980)

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APPENDIX A

TEST PLAN FOR
STOICHIOMETRIC DIESEL
PHASE II SBIR PROGRAM

BY:

DAVE MCNULTY

PROGRAM MANAGER

ADIABATICS, INC.

FOR:

U.S. ARMY TACOM

CONTRACT # DAAE07-89-C-R014

I. Objectives: 1. Shake-down Test Cell and systems with stock Caterpillar 1Y73.

2. Collect data for baseline and test builds at high loads and Stoichiometric air-fuel ratio.

II. Approach

A conventional water-cooled diesel will have a BSFC vs. fuel-air ratio (F/A) characteristic as shown in Figure 1. It indicates that BSFC will minimize when the F/A is around .03. As the mixture is made richer at constant fuel flow, the BSFC will rise. Since fuel flow is fixed, the brake power will fall if rpm is fixed. This requires torque to drop. Upon reaching Stoichiometric F/A under these conditions, the power has dropped dramatically and black smoke from the engine has very likely become intolerable. Combustion theory for the diesel engine has explained this phenomenon as one in which the diesel fuel needs time to evaporate and mix with the available oxygen in order to combust with it. Due to the fuel being injected in fine droplet form, a very rich F/A zone near the injector tip is created along with a potentially very lean F/A zone near the cylinder wall. Thus part of the fuel near the injector tip very quickly consumes all the available oxygen near the tip leaving some unburnt and perhaps unevaporated fuel. This remaining fuel combusts as turbulence and bulk fluid motion mix the available oxygen further away from the injector with the unburnt fuel. Thus the greater the excess air the easier it is for the diesel engine to combust its fuel since it is easier for the fuel to find oxygen to combust with.

The above described behavior of diesel combustion results in slower heat release rates as F/A is made richer. This is why BSFC increases; fuel is not burned early enough in the cycle to get full expansion stroke on the energy thus released. One must increase the heat release rate at rich F/A in order to efficiently attain Stoichiometric operation and change the BSFC vs F/A curve to look like the dashed line in Figure 1.

Thus the hardware to be used in these tests will be aimed at enhancing three processes:

1. fuel evaporation
2. Reaction rates of fuel oxidation
3. Mixing intensity of fuel-air charge

A special piston has been designed for builds II through V which has an air-gap insulated combustion bowl. Figure 2 shows the piston construction. This piston allows a great variety of bowl shapes and volumes to be used. The air-gap insulation will result in a very hot surface in the piston bowl. This hot surface will increase the rate of fuel droplet evaporation and shorten the ignition delay period.

In addition the air-gap insulation will increase the reaction rate of the fuel-air mixture. The higher temperatures in the combustion bowl due to the insulation will cause this.

Finally the mixing will be controlled by the geometry of the piston bowl and the turbulence generated in the injection process. Different bowls will be tested to optimize combustion. Different injector nozzles will be used to vary the mixing turbulence during injection by varying the number of spray jets. Nozzles with the same number of spray holes but different spray hole diameters will also be used. This will vary the mixing turbulence by varying the jet velocity.

Changing these various piston bowls and injector nozzles in a logical sequence will yield data which will show trends of what hardware configuration would best achieve stoichiometric combustion.

For builds VI through VIII processes 1 and 2 above will be enhanced by a hot hastelloy-x TICS chamber shown in Figure 8. This chamber has a spacer which can be used to increase the volume of the TICS. This spacer will also affect process 3 above.

All components (with the exception of the TICS chamber) will be coated with ceramic thermal insulation to reduce combustion heat loss and there by raise combustion temperatures to aid processes 1 and 2.

III. Hardware

Non-Stock Piston

A three piece piston has been designed and fabricated for testing builds II through V. The design was such that 3 requirements could be met.

1. Air gap insulation of the combustion bowl
2. Allow the change of bowl design without the manufacture of different pistons
3. Minimize "dead" space in the clearance volume

Three combustion bowls will be tested, they are shown as bowls 1, 2, and 3 in Figures 3 through 5. Bowls 1 and 3 are the same material (Hastelloy-X) and shape but with different bowl exit (throat) diameters. Bowl 1 and 2 have the same shape but are different in material and insulation. Bowl 1 is Hastelloy-X while bowl 2 is thermal barrier coated titanium.

These three bowls will show effects of bowl throat diameter and surface insulation on combustion. Compression ratio will be held constant. Different bowl shapes could be tried but due to the endless possibilities, this single representative shape will be used unless testing warrants a change in shape.

For builds VI through VIII the piston will consist of the stock aluminum piston modified for thermal barrier coating on the piston top and a piston bowl volume of two different valves. Piston #1 shown in Figure 9 will be designed for a compression ratio of 14.2 with the stock prechamber volume and a volume ratio of .3. Piston #2 shown in Figure 10 will be designed for the same compression ratio but with a non-stock volume ratio of .5 which reduces the volume of the piston bowl.

Non-Stock Liner, Head, and Valves

The liner will be thin thermal barrier coated. This will maximize volumetric efficiency while at the same time provide good insulation during combustion, when it is most important.

Head fire deck will be thick thermal barrier coated. The intake and exhaust ports will be insulated also. This will allow the head to operate uncooled and provide maximum combustion insulation. The port insulation will maximize volumetric efficiency and protect the cast iron in the cylinder head from the extreme exhaust temperatures at stoichiometric fuel-air ratio.

Fuel System

A Bosch fuel pump, Bosch type injector, and 4 different injector nozzles will comprise the fuel system. The injector is shown in Figure 6. The nozzles (A, B, C, and D) are shown in Figure 7. These nozzles will allow assessment of mixing in two ways. One is by varying the number of holes but maintaining a constant flow area. This can be done with nozzles A, B, and C. Secondly, injection pressure will be assessed by varying the flow area but maintaining a constant number of holes. This can be done by nozzles B and D.

TICS Chambers

For builds II through V the TICS is in the piston top in the form of the hastelloy-x bowl. However, builds VI through VIII the TICS is in the cylinder head, similar to a prechamber. Figure 8 shows a TICS design for use in a watercooled cast iron head. The air gaps formed in the TICS sections give thermal insulation from the water-cooling and allow the TICS to attain high temperatures. The TICS has a spacer which allows the volume to be changed by use of or omitting the spacer. The spacer allows a volume ratio of prechamber to total clearance volume (at TDC) to be either .5 or .3 for the stock build. This allows engine evaluation of the effect of prechamber volume and volume ratio on engine performance.

IV. Testing

Build I: Stock Caterpillar 1Y73

The engine will be built up to a stock, watercooled 1Y73 configuration. Limited data will be taken from this build. It will be used as a vehicle for test cell shake-down. Data sufficient to verify proper engine and system performance will be taken.

Build II: Baseline

Objective: To generate data for comparison to subsequent builds

Components: Bosch fuel pump
Bosch type injector
Coated cylinder head (for injector)
Hastelloy-X Bowl - Piston (Bowl #1)
Liner, Valves - Stock

The piston, since untried to this point, shall be placed in the engine. The engine speed, under light load shall be increased gradually to 1800 rpm for maximum inertial load on the piston bowl. At optimum timing load shall be increased gradually (1/4, 1/2, 3/4, full) to full load so as to increase temperatures in the piston bowl, top, and skirt. The increase temperature of the materials will lower the strength in their respective parts. Once full load is attained, at 1800 rpm, the load will be further increased until stoichiometric air-fuel ratio is attained.

The conditions will be as follows:

<u>Temperatures</u>

Engine water out:	195^{o}F
Engine oil to bearings:	205^{o}F
Intake surge tank temperature:	255^{o}F

<u>Pressures</u>

Intake surge tank:	11 psi g.
Exhaust restriction:	11 psi g.

<u>Load</u>

1/4, 31 ft. - lb
1/2, 61 ft. - lb
3/4, 92 ft. - lb
full. 122 ft. - lb

Upon successful completion of this test sequence, baseline performance data will be taken. Starting with nozzle "B" the engine will again be brought to 1800 rpm. Fuel-air ratio sweeps from about .025 to .067 (Stoichiometric) will be made at best timing by adjusting boost pressure with fixed inlet air temperature at 1/4 load points up to full load (42 hp). This test sequence will be repeated with nozzles A, C, and D if trends point to a better performance with either fewer holes or change in hole diameter.

Test conditions will be:

<u>Temperatures</u>

Engine water out:	195^{o}F
Oil to bearings:	205^{o}F
Intake Surge tank:	70-450^{o}F

Pressures

Intake Surge Tank: 0-11psi g.
Exhaust Restriction: 1:1 ratio to intake

This test sequence will generate data for comparison to subsequent builds. The comparison will show the trends in performance as the engine is made to operate under stoichiometric conditions and indicate what variables to control for stoichiometric operation.

Build III: Stoichiometric Engine #1

Objective: Test for the effect of uncooled, insulated operation.

Components: Bosch fuel pump
Bosch type injector
Coated cylinder head
Coated valves
Coated liner
Hastelloy-X bowl-piston (bowl #1)

This build will be uncooled and will have coated components for the liner, head, and valves. Starting with nozzle "B" the engine will be started and warmed up. Speed will be increased under light load up to 1800 rpm. Fuel-air ratio sweeps will be made by adjusting boost pressure with fixed intake air temperature at optimum timing. Proceeding in 1/4 load increments load shall be increased from 1/4 to full load (42 hp). This test sequence will be performed with each of the 4 different nozzles (A, B, C, and D) if trends warrant.

This test shall be partially repeated by running the full load point with a different intake air temperature. Upon measuring the effect of intake air temperature at constant fuel-air ratios a decision will be made as to whether to change intake air temperature again.

Test conditions:

Temperatures

Engine oil to bearings: 205°F
Intake surge tank: 70-255°F

Pressures

Intake surge tank: 0-11 psi x g.
Exhaust restriction: 0-11 psi x g. (1:1 pressure ratio across engine)

Build IV: Stoichiometric Engine #2

Objective: Show the effect of degree of insulation on piston bowl on performance

Components: Bosch fuel pump
Bosch type injector
Coated cylinder, valves, and liner
coated titanium bowl-piston (bowl #2)

This build will be identical to build III except the piston will have a titanium bowl coated with thermal insulating ceramic. This build will be tested in the same way as build III.

Build V: Stoichiometric Engine 3

Objective: To show the effect of bowl throat diameter on performance.

Components: Bosch fuel pump
Bosch type injector
Coated cylinder head, valves and liner
Hastelloy-X narrow throat bowl (bowl 3)

This build will be identical to build III except it will have a narrow throat in piston bowl 3 compared to bowl 1. This build will be tested in the same way as build III.

Build VI: Stoichiometric Engine #4

Objective: To investigate the performance of an IDI engine with TICS in the Lead.

Components: Bosch fuel pump
Bosch type injector
Coated, water-cooled cylinder head, liner
Coated valves
Hastelloy-X TICS chamber 35% volume ratio
Coated piston #1 (Figure 9)

Taking fuel flow, intake pressure and intake temperature as independent variables the effects of fuel flow, air/fuel ratio, and intake air temperature will be studied at 1800 rpm and 3/4 (92 ft-lb) and full (122 ft-lb) load torques. These data will be used to collect data at stoichiometric air/fuel ratio at the highest possible peak cylinder pressure the fuel system can deliver and the engine can withstand (2000 psi).

Build VII: Stoichiometric Engine #5

Objective: To investigate the performance of an IDI engine with a large TICS volume but low compression ratio.

Components: Bosch fuel pump
Bosch type injector
Water-cooled cylinder head, liner
Coated Valves
Hastelloy-X TICS chamber
(84 cc volume)
coated piston #1

This build will be identical to build VI except a larger TICS volume will be used. By using the same piston as build VI, the compression ratio will be substantially lowered from build VI (from 14.2 to 11.5). Test data will be collected in the same manner as for build VI.

Build VIII: Stoichiometric Engine #6

Objective: To investigate the performance of an IDI engine with a large TICS volume but same compression ratio as Build VI.

Components:
- Bosch fuel pump
- Bosch type injector
- Water-cooled cylinder, liner
- Coated valves
- Hastelloy-X TICS chamber (84 cc)
- Coated piston #2

This build will be identical to build VII except the piston will be replaced with one which raises the compression ratio back to that of build VI. This piston is shown in Figure 10.

Data/Program Review

Upon completion of these builds a data and program review will be held to evaluate data trends and to determine need for further testing.

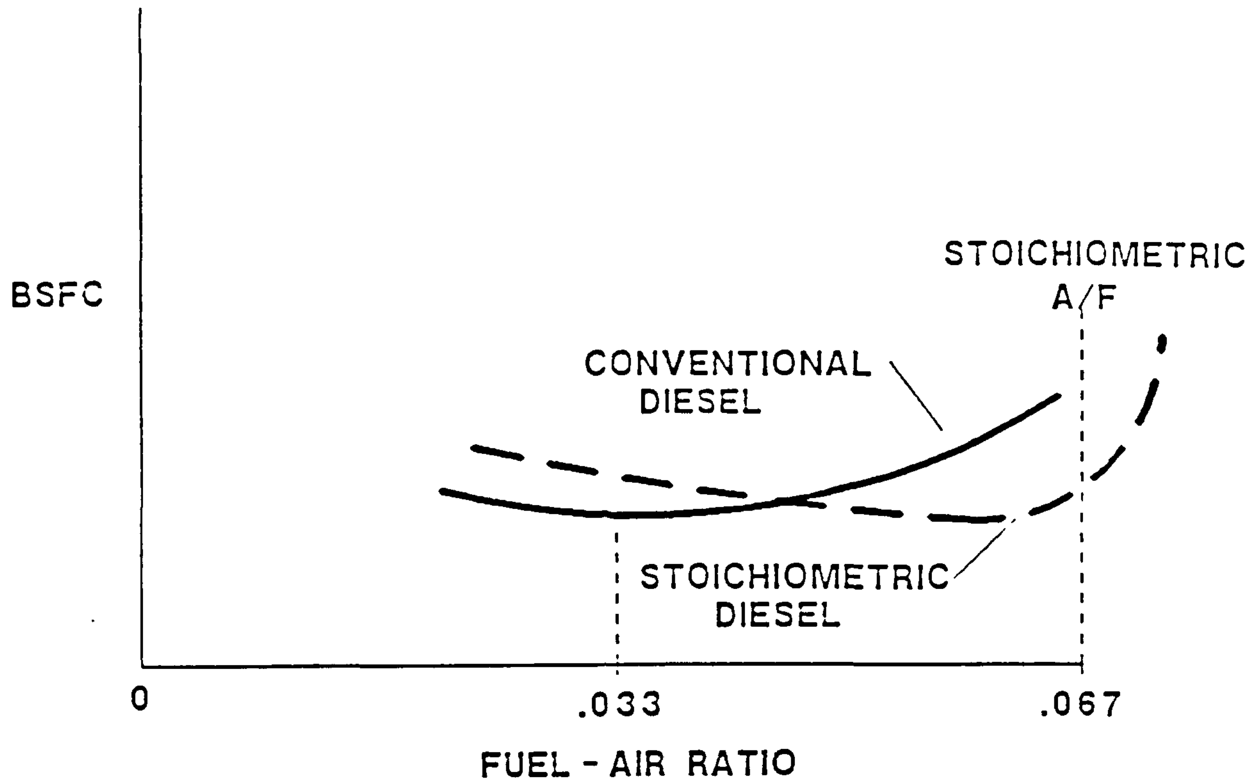


Figure 1. Behavior of BSFC with Fuel-air Ratio

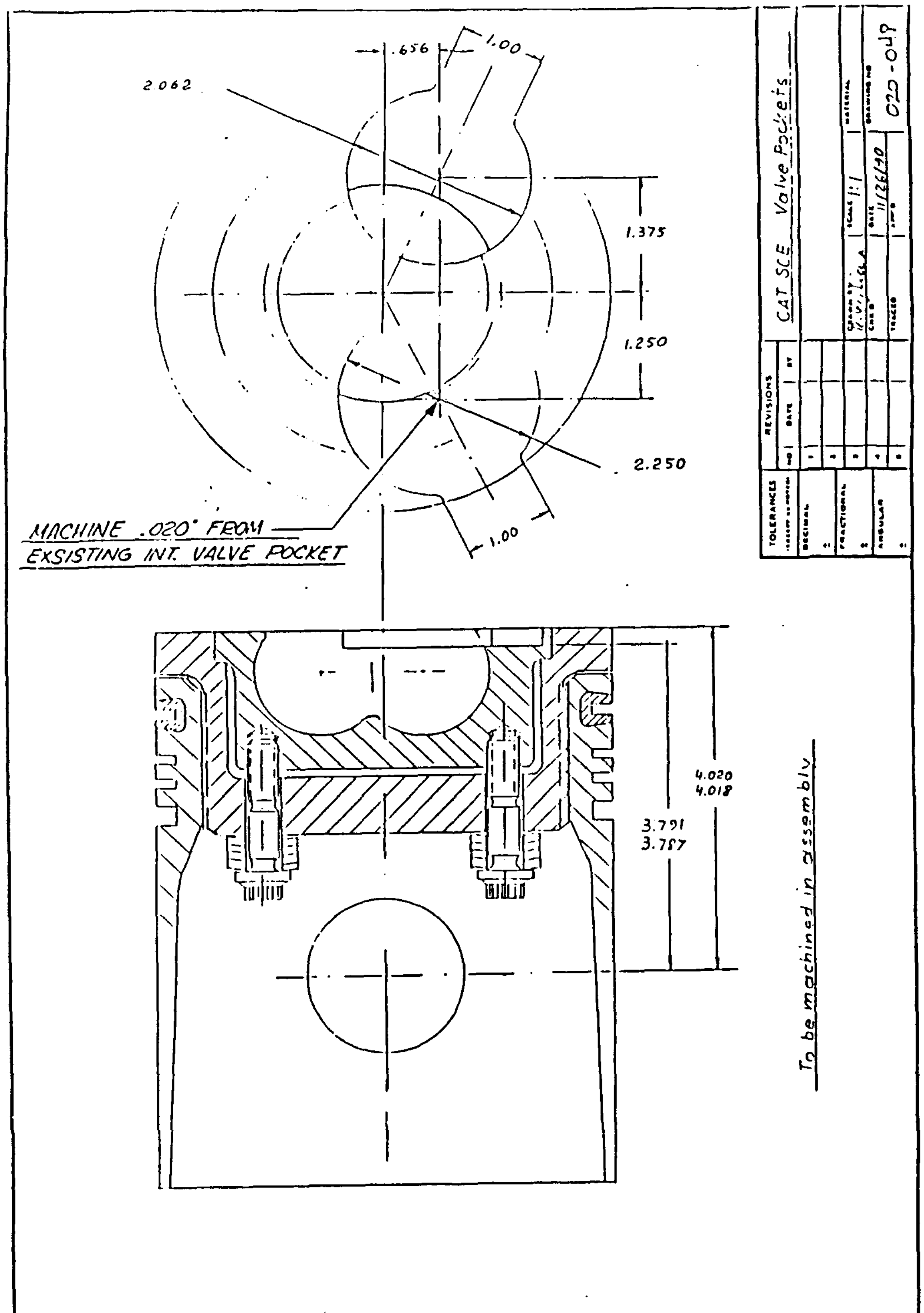


Figure 2. Three Piece Piston Design

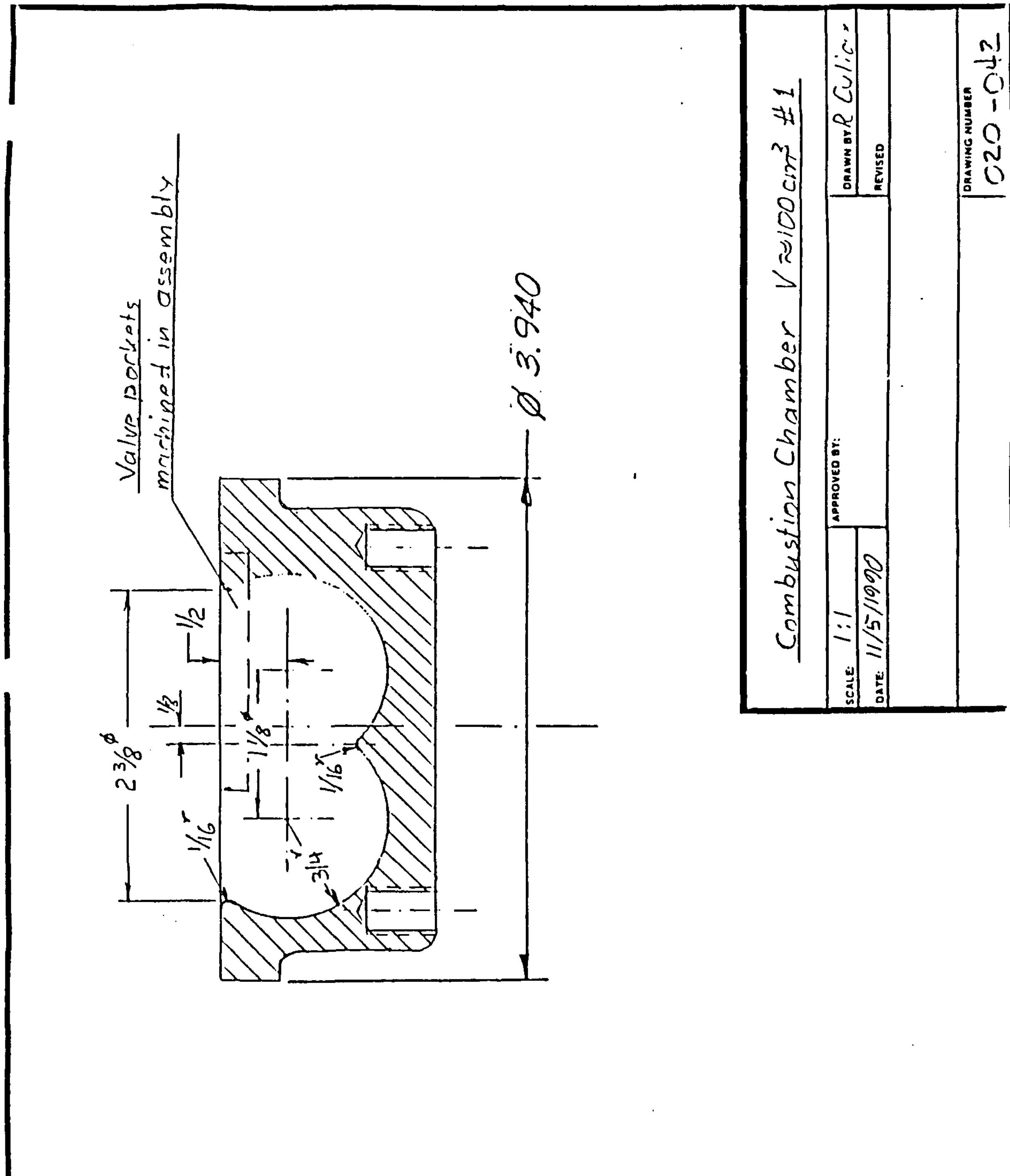


Figure 3. Bowl #1 - Hastelloy X

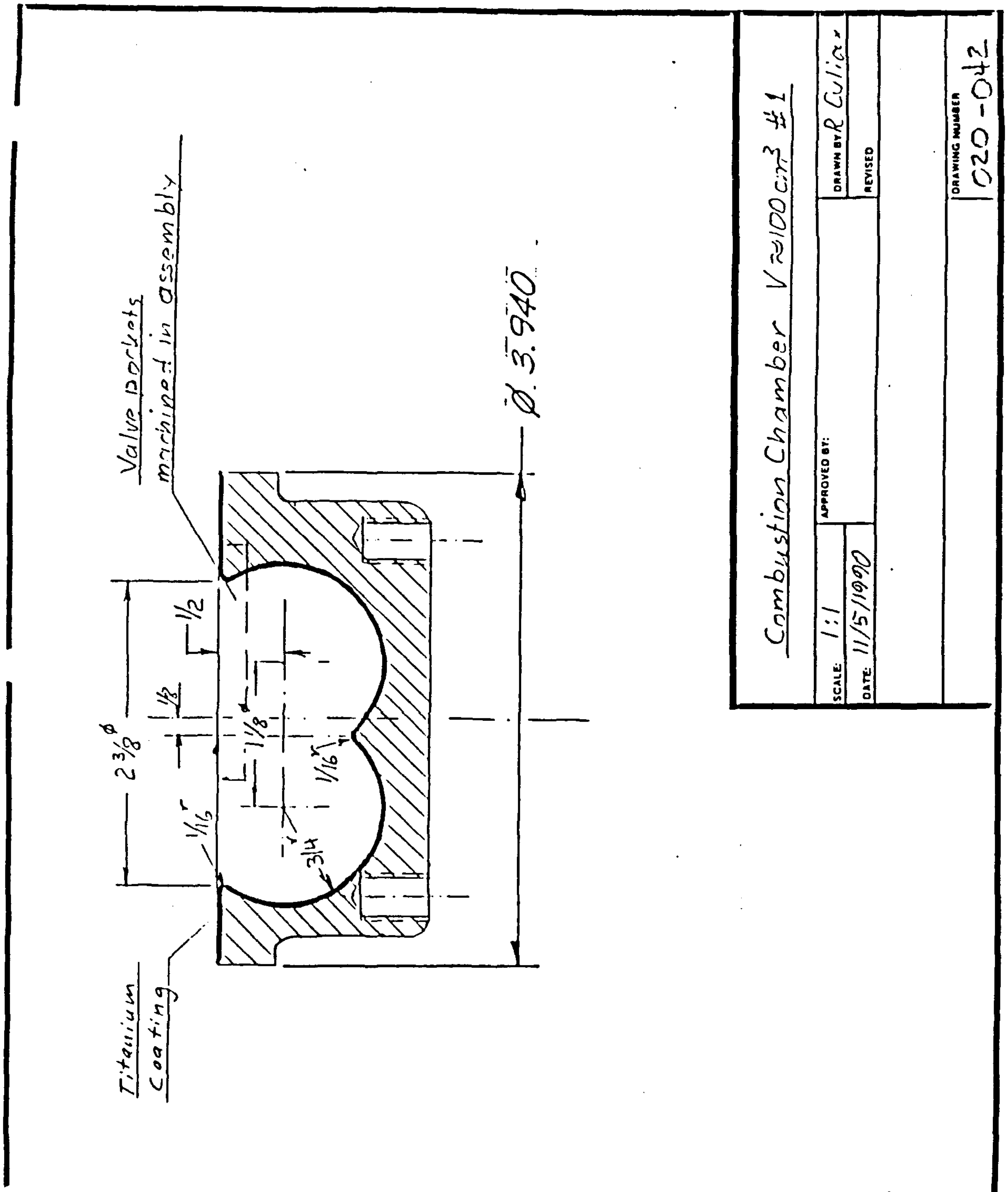


Figure 4. Bowl #2 - Titanium with Thermal Coating

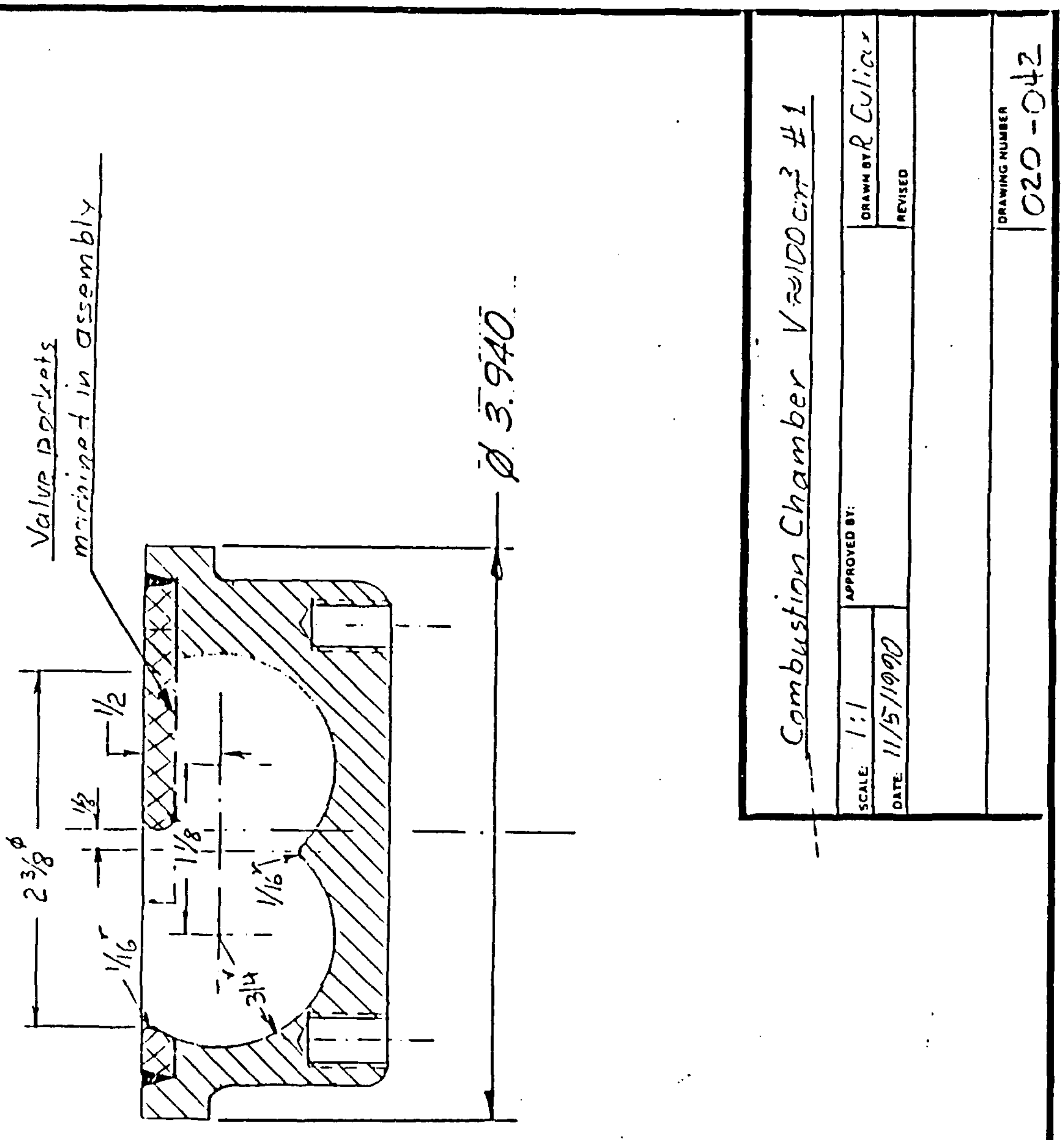


Figure 5. Bowl #3 - Hastelloy X with Narrow Throat

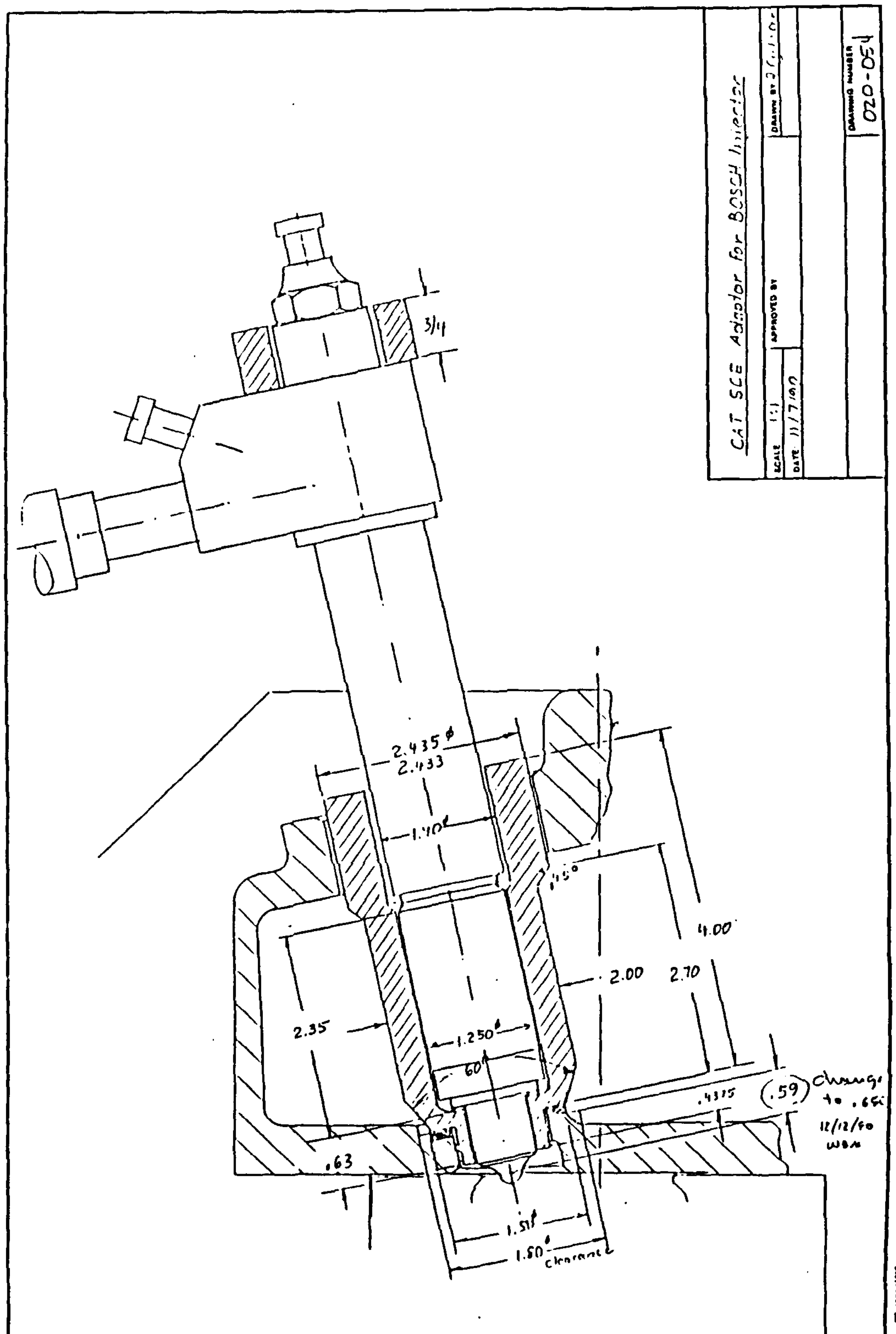
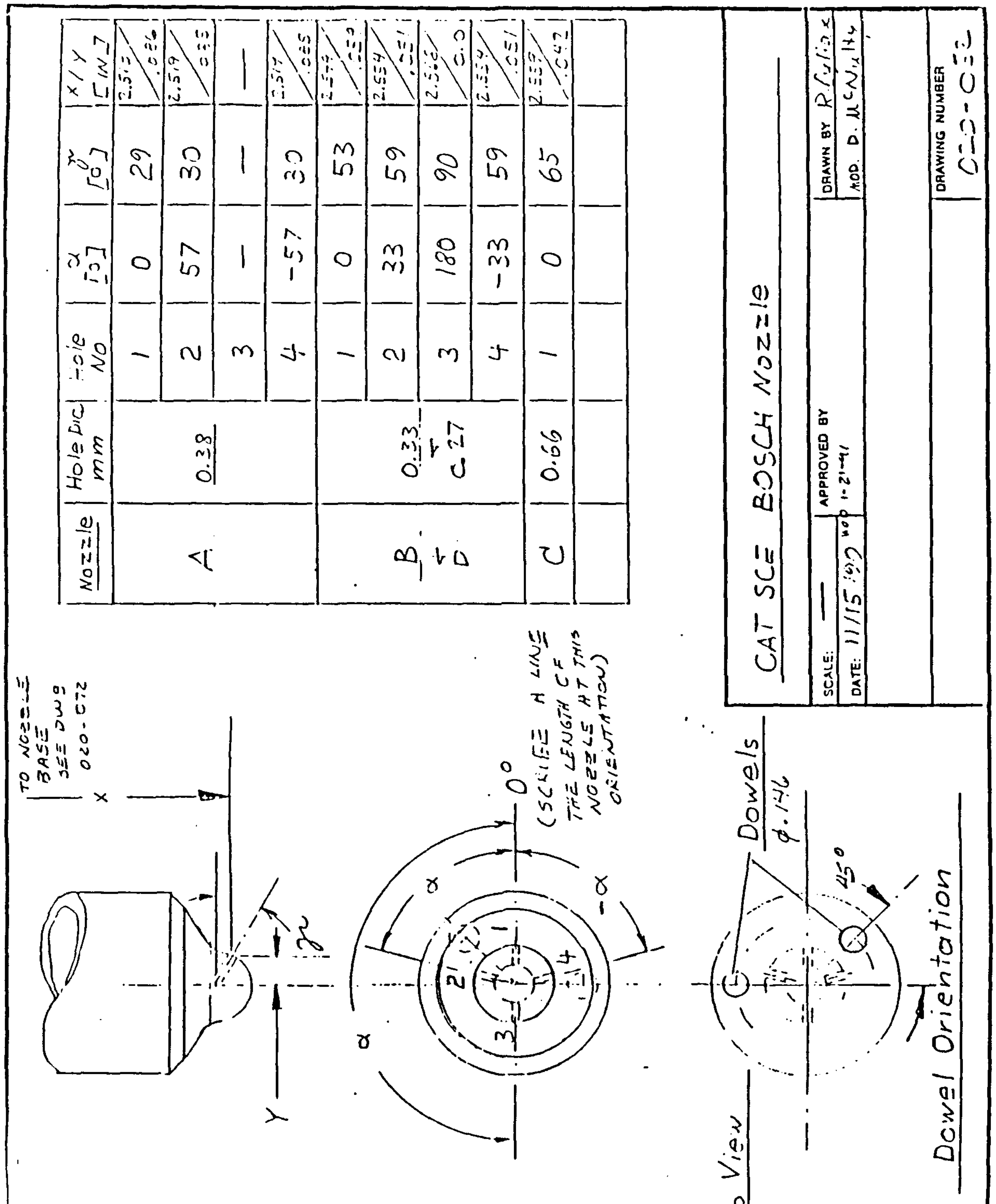


Figure 6. Bosch Type Injector in 1Y73 Cylinder Head



Nozzle	Hole Dia mm	Hole No	α [°]	γ [°]	X/Y [IN]
A	0.38	1	0	29	2.513/.036
		2	57	30	2.519/.033
		3	—	—	—
		4	-57	30	2.517/.035
B + D	0.33 + 0.27	1	0	53	2.549/.053
		2	33	59	2.554/.051
		3	180	90	2.562/0.0
		4	-33	59	2.554/.051
C	0.66	1	0	65	2.559/.042

Figure 7. Injector Nozzle Hole Configurations

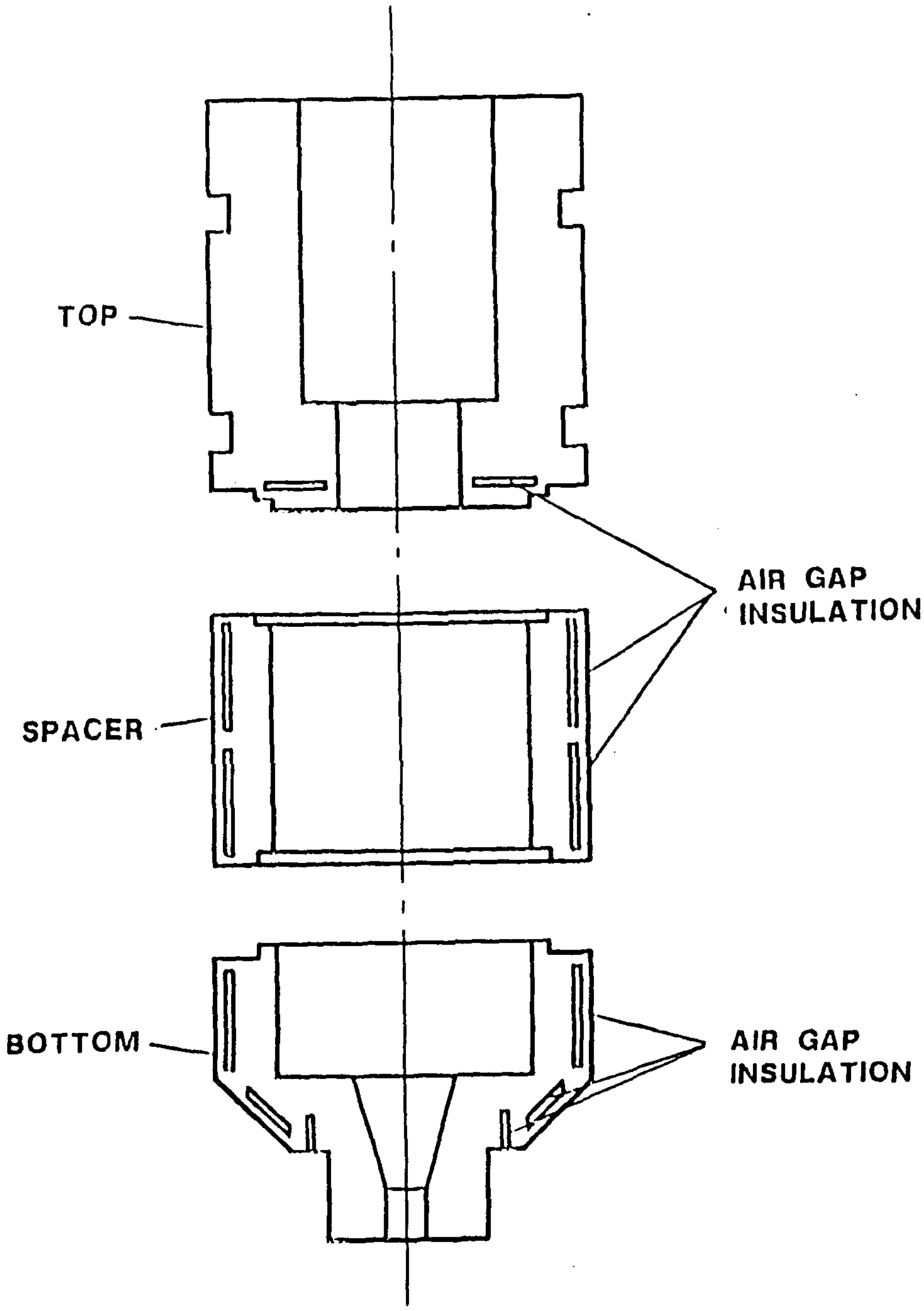


FIGURE 8: TICS CHAMBER WITH SPACER FOR STOCK AND 50% VOLUME RATIO

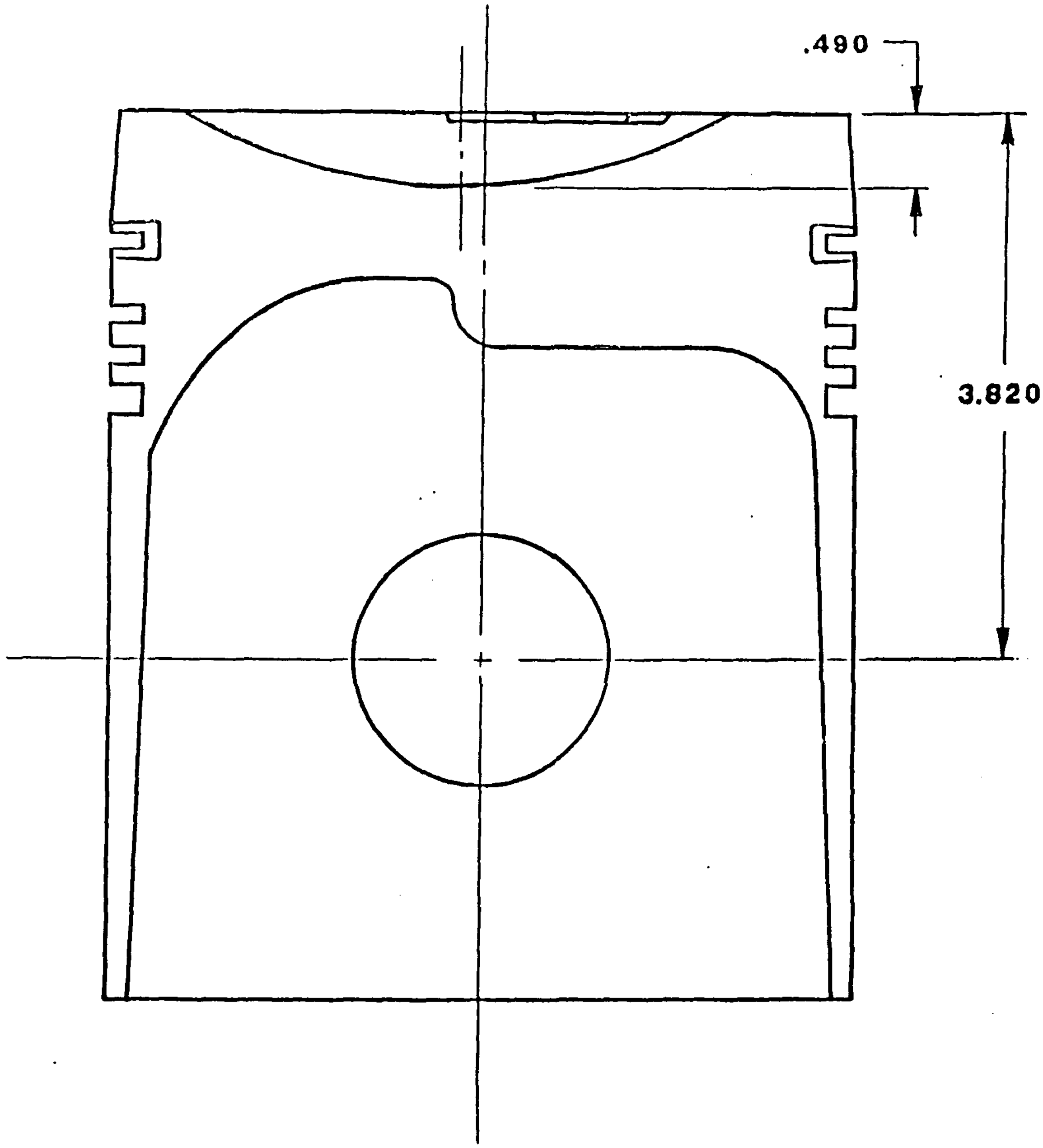


FIGURE 9: PISTON #1 - STOCK CLEARANCE VOLUME

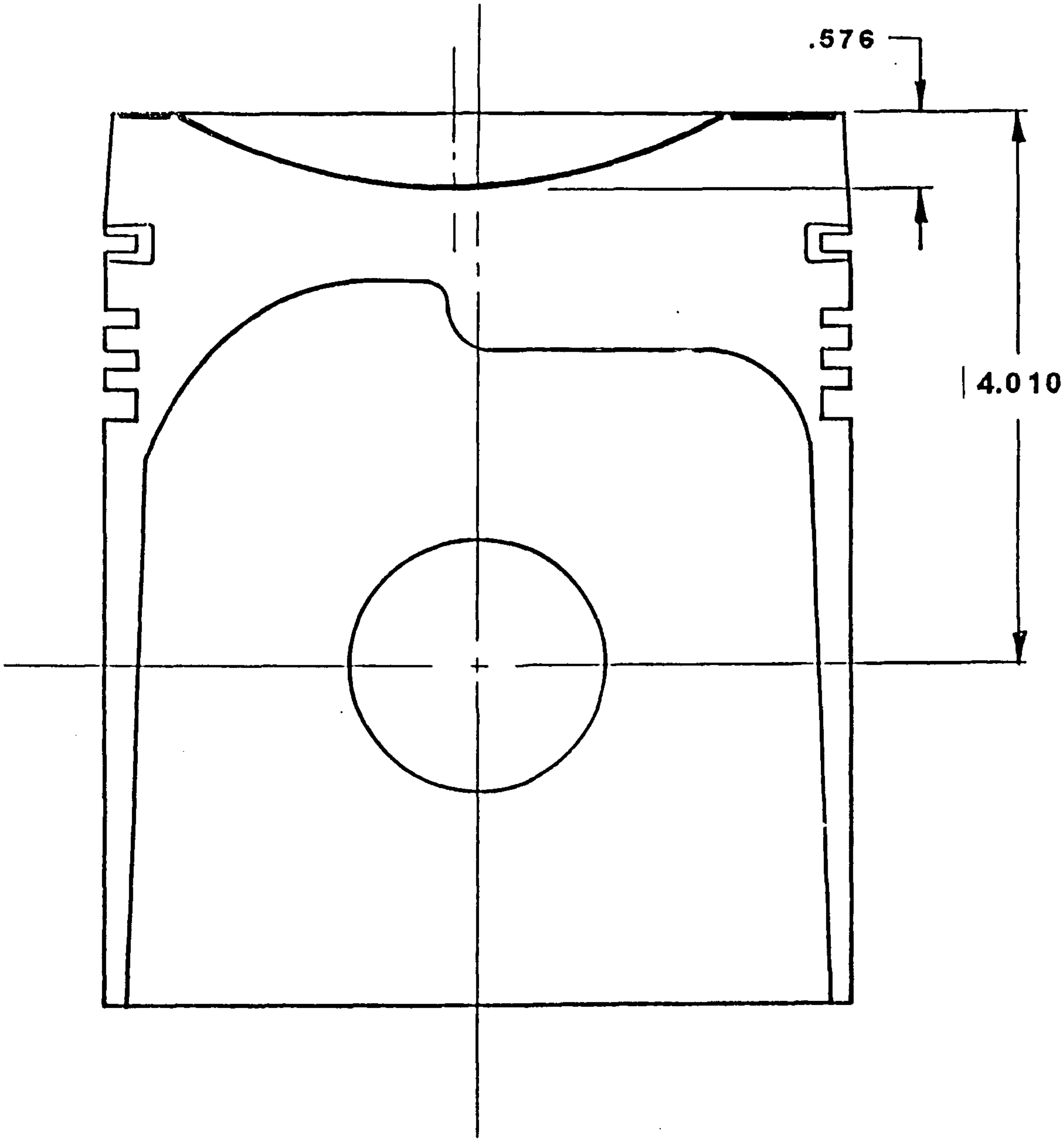


FIGURE 10: PISTON #2 - FOR 50% VOLUME RATIO
TICS CHAMBER

APPENDIX B

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Date	Time of Day	Pk Inj Pressure (psi)	Inj Duration (ca)	Injection Timing deg BTDC	RPM	Torque (N*m)
BUILD I: STOCK CATERPILLAR 1Y73							
1	1/23/91	12:00	NA		8	1781	86.8
2	1/24/91	11:00	NA		8	1800	85.4
3	1/24/91	12:09	NA		8	1790	124.8
4	1/24/91	12:46	NA		8	1788	164.1
5	1/30/91	5:09	NA		8	1798	164.1
6	2/4/91	3:54	NA		8	1814	157.3
7	2/4/91	4:51	NA		8	1800	169.5
8	2/4/91	5:29	NA		8	1805	183.1
9	2/4/91	5:51	NA		8	1811	189.8
10	2/5/91	3:02	NA		8	1808	149.2
BUILD IIA: DI; HASTELLOY-X BOWL #1, BOSCH FUEL PUMP AND INJECTOR, 4 HOLE NOZZLE "B", VARIABLE TIMING DEVICE							
11	2/19/91	4:46	NA		13	1407	84.1
12	2/20/91	5:19	NA	25	15	1800	33.9
		secondary inj		22		1800	
BUILD IIB: 6 HOLE NOZZLE							
13	3/8/91	12:35	NA	25	15	1790	89.5
14	3/8/91	1:41	NA	33	27	1809	119.3
15	3/8/91	2:52	NA	33	27	1801	122.[illegible]
16	3/12/91	1:30	NA		25	1798	119.3
17	3/12/91	1:55	NA	28	25	1802	120.7
18	3/12/91	3:20	NA		24	1806	120.7
19	3/12/91	3:56	NA		24	1805	113.9
BUILD IIC: 6 HOLE NOZZLE, .002 PER SIDE ADDITIONAL SKIRT CLEARANCE, ROLL PIN PISTON TOP RETAINERS NERS, HEATER ON/ HEATER OFF							
20	3/29/91	11:00	NA	24	23	1803	122.0
21	3/29/91	12:54	NA	25	23	1804	120.3
22	3/29/91	1:50	NA	25	23	1806	116.6
23	3/29/91	2:40	NA	34	35	1806	135.6
24	3/29/91	3:20	NA	31	27	1806	137.0
BUILD VIA: TICS PRECHAMBER 35% VR, FULL ADIABATIC CERAMIC INLAY PRECHAMBER SEAL, 1 HOLE NOZZLE (.026 DIA)							
25	5/2/91	10:00	NA	?	?	1500	94.9

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Date	Time of Day	Pk Inj Pressure (psi)	Inj Duration (ca)	Injection Timing deg BTDC	RPM	Torque (N*m)
BUILD VIB: TICS PRECHAMBER 35% VR, COOLED BLOCK, ADIABATIC HEAD BELLEVILLE STACK WAS 3 STACKS OF 3, 1 TURN PRELOAD							
26	5/9/91	4:14	NA	42	9	1800	135.6
27	5/9/91	4:48	NA	47	0	1794	113.9
BUILD VIC: SAME AS VI B BUT BELLEVILLE STACK WAS 7 STACKS OF 4 1 TURN PRELOAD							
28	5/16/91	4:00	NA	40	8	1789	158.3
29	5/16/91	4:56	NA	40	8	1789	154.6
BUILD VID: SAME AS VI C BUT WITH AIR GAP PRECHAMBER SEAL							
30	5/17/91	10:00	NA	40	7	1788	154.6
31	5/17/91	4:20	NA	40	8	1785	128.1
BUILD VIE: SAME AS VI D BUT WATER-COOLED HEAD AND LINER							
34	5/28/91	1:05	NA		11	1789	115.9
33	5/28/91	12:40	NA		11	1798	127.5
32	5/28/91	12:05	NA		11	1804	138.3
CORRECTED FOR FUEL FLOW AND RPM							
34	5/28/91	1:05	NA		11	1804	115.9
33	5/28/91	12:40	NA		11	1804	127.5
32	5/28/91	12.05	NA		11	1804	138.3
BLD. VIIA: ALL WATER COOLED; 84 CC (BIG) PC SAME PISTON AS VI E 1 1/8 TURN PRELOAD, 1 HOLE NOZZLE (.026 DIA)							
TIMING TEST							
36	6/4/91	11.09	NA	38	-1	1796	118.7
37	6/4/91	11:29	NA	39	5	1796	129.5
35	6/4/91	10:39	NA	40	12	1799	132.2
INTAKE TEMP TEST							
35	6/4/91	10:39	NA	40	12	1799	132.2
38	6/4/91	12:15	NA	39	13	1796	131.1
39	6/4/91	1:30	NA	39	12	1796	127.9
STOICHIOMETRIC AND MINIMUM SMOKE TEST							
40	6/4/91	2:46	NA	39	8	1798	122.0
41	6/4/91	3:10	NA	39	-1	1789	109.2
42	6/4/91	3:40	NA	39	-1	1791	107.1
43	6/5/91	11:37	NA	39	12	1793	125.4

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Date	Time of Day	Pk Inj Pressure (psi)	Inj Duration (ca)	Injection Timing deg BTDC	RPM	Torque (N*m)
BLD. VIIB:	SAME AS VII A BUT STOCK PISTON WITH .005 OVER LINER BORE BUTTERFLY VALVE TROUBLE						
44	6/12/91	10:48	NA	39	13	1806	124.5
45	6/12/91	11:26	NA	53	13	1802	182.2
46	6/12/91	12:05	NA	59	13	1804	216.3
BLD. VIIC:	SAME AS VII B BUT TOP AND FIRST INTER. RING LANDS CUT .010 HIGH POWER DENSITY TEST						
47	6/19/91	10:54	NA	40	13	1807	126.8
48	6/19/91	1:34	NA	58	18	1803	209.3
49	6/19/91	2:15	NA	49	18	1801	175.6
50	6/19/91	3:08	NA	41	18	1801	128.8
BLD. VIID:	SAME AS VII C BUT WITH SPACER AND MOLYBDENUM RODS IN PC .500 THROAT ENLARGED FROM .300; FUEL ADDITIVE TESTS						
	DIESEL FUEL, ADDITIVE, AND RODS (???)						
51	6/25/91	4:30	NA	44	19	1801	119.7
	DIESEL FUEL AND RODS (???)						
52	6/26/91	12:15	NA	38	17	1804	138.5
	DIESEL FUEL ONLY, TIMING AND A/F TESTS						
53	6/27/91	10:11	NA	38	17	1801	140.4
54	6/27/91	11:18	NA	34	16	1801	97.5
55	6/27/91	11:40	NA	35	10	1802	93.6
56	6/27/91	11:55	NA	35	-1	1802	86.6
	DIESEL FUEL, ADDITIVE, BUT NO RODS						
57	6/27/91	3:38	NA	43	19	1602	106.4
58	6/27/91	3:54	NA	39	18	1808	92.4
59	6/27/91	4:08	NA	42	18	1801	98.2
BLD.VIIIA:	FLAT TOP PISTON, FLUSH VALVES, BIG VOL PC, .5 TH DIA						
60	7/17/91	4:03	NA	41	19	1803	119.6
	A/F RATIO TESTS						
61	7/18/91	11:40	NA	41	19	1803	119.5
62	7/18/91	12:40	NA	41	19	1809	111.7
63	7/18/91	1:30	NA	41	19	1809	103.0

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Date	Time of Day	Pk Inj Pressure (psi)	Inj Duration (ca)	Injection Timing deg BTDC	RPM	Torque (N*m)
		TIMING TEST					
64	7/19/91	11:17	NA	41	18	1801	99.6
65	7/19/91	11:45	NA	41	9	1801	92.3
66	7/19/91	12:06	NA	41	0	1800	74.5
		MAX POWER					
67	7/19/91	12:40	NA	53	20	1801	147.6
		COOLED HEAD, UNCOOLED, NO DATA TAKEN DUE TO EXCESSIVE TRR TEMPERATURES					
68	8/1/91						
3LD. VIIE:	SAME AS VII C BUT WITH INSULATED CYL HEAD INJECTOR NOZZLE SPRAY HOLE DIA TESTS, OPT TMG						
		INJECTOR NOZZLE SPRAY HOLE .026					
71	8/20/91	4:00	NA	47	18	1800	145.7
		INJECTOR NOZZLE SPRAY HOLE .028					
69	8/19/91	3:30	NA	45	16	1800	151.3
		INJECTOR NOZZLE SPRAY HOLE .030					
70	8/20/91	12:00	NA	38.	9	1800	151.8
3LD. VIIF:	SAME AS VII E BUT WITH PSZ UNDENSIFIED EXH VALVE INJECTOR NOZZLE, 6 SPRAY HOLES @ .012 DIDN'T RUN DATA DUE TO EXCESSIVE SMOKE AND HIGH EXHAUST TEMPERATURE						
72	8/21/91						
3LD. VIIF:	SAME AS VII E BUT WITH .030 HOLE NOZZLE INTAKE TEMPERATURE, CONSTANT A/F TEST						
73	8/23/91	10:50	NA	37	9	1801	148.4
74	8/23/91	12:18	NA	38	9	1800	146.8
75	8/23/91	1:23	NA	38	9	1801	142.6
76	8/23/91	4:07	NA	37	10	1801	141.0
77	8/26/91	12:13	NA	37	10	1801	139.8

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Date	Time of Day	Pk Inj Pressure (psi)	Inj Duration (ca)	Injection Timing deg BTDC	RPM	Torque (N*m)
BLD. IXA:	STOCK CAT HEAD, WC, STOCK INJECTOR NOZZLE AMBAC FUEL PUMP, A/F RATIO EFFECT, CONST FUEL FLOW						
78	8/28/91	3:18	4488	43	12	1800	151.0
79	8/28/91	3:44	4460	43 GUESS	12 GUESS	1801	145.1
	ENGINE RAN OUT OF WATER, HOT SHUT DOWN						
80	8/28/91	4:13	4462	44	13	1801	130.7
BLD. XA:	STOCK CAT HEAD, WC, STOCK INJECTOR NOZZLE STOCK FUEL PUMP, A/F RATIO EFFECT, CONST FUEL FLOW						
81	9/04/91	11:14	6512	41	7	1800	161.5
82	9/04/91	11:49	6477	41	7	1801	167.6
83	9/04/91	12:16	6631	41	7	1800	173.8
BLD. XIA:	84 cc PC, BOSCH INJECTOR, .030 SINGLE HOLE NOZZLE STOCK FUEL PUMP, A/F RATIO EFFECT, CONST FUEL FLOW						
84	9/17/91	11:53	5256	35	12	1795	153.8
85	9/17/91	12:26	5390	34	11	1801	140.6

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Torque (lbf*ft)	BHP (kW)	BHP (hp)	BMEP (kPa)	BMEP (psi)	IMEP (kPa)	IMEP (psi)
BUILD I:							
1	64.0	16.2	21.7	496.3	72.0		
2	63.0	16.1	21.6	488.5	70.9		
3	92.0	23.4	31.4	713.4	103.5		
4	121.0	30.7	41.2	938.3	136.1		
5	121.0	30.9	41.4	938.3	136.1		
6	116.0	29.9	40.1	899.5	130.5		
7	125.0	31.9	42.8	969.3	140.6		
8	135.0	34.6	46.4	1046.8	151.8		
9	140.0	36.0	48.3	1085.6	157.4		
10	110.0	28.2	37.9	853.0	123.7		
BUILD IIA							
11	62.0	12.4	16.6	480.8	69.7		
12	25.0	6.4	8.6	193.9	28.1		
BUILD IIB							
13	66.0	16.8	22.5	511.8	74.2		
14	88.0	22.6	30.3	682.4	99.0		
15	90.0	23.0	30.9	697.9	101.2		
16	88	22.5	30.1	682.4	99.0		
17	89	22.8	30.5	690.1	100.1		
18	89.	22.8	30.6	690.1	100.1		
19	84.0	21.5	28.9	651.4	94.5		
BUILD IIC	SAME A/F RATIO						
20	90.0	23.0	30.9	697.9	101.2		
21	88.8	22.7	30.5	688.2	99.8		
22	86.0	22.1	29.6	666.9	96.7		
23	100.0	25.6	34.4	775.4	112.5		
24	101.0	25.9	34.7	783.2	113.6		
BUILD VIA							
25	70.0	14.9	20.0	542.8	78.7		

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Torque (lbf*ft)	BHP (kW)	BHP (hp)	BMEP (kPa)	BMEP (psi)	IMEP (kPa)	IMEP (psi)
BUILD VIB							
26	100.0	25.6	34.3	775.4	112.5		
27	84.0	21.4	28.7	651.4	94.5		
BUILD VIC							
28	116.8	29.7	39.8	905.3	131.3		
29	114.0	29.0	38.8	884.0	128.2		
BUILD VID							
30	114.0	28.9	38.8	884.0	128.2		
31	94.5	23.9	32.1	732.8	106.3		
BUILD VIE							
34	85.5	21.7	29.1	663.0	96.2		
33	94.0	24.0	32.2	728.9	105.7		
32	102.0	26.1	35.0	790.9	114.7		
34	85.5	21.9	29.4	663.0	96.2		
33	94.0	24.1	32.3	728.9	105.7		
32	102.0	26.1	35.0	790.9	114.7		
BLD. VIIA							
36	87.5	22.3	29.9	678.5	98.4		
37	95.5	24.4	32.7	740.5	107.4		
35	97.5	24.9	33.4	756.0	109.7		
35	97.5	24.9	33.4	756.0	109.7		
38	96.7	24.6	33.1	749.6	108.7		
39	94.3	24.1	32.3	731.5	106.1		
40	90.0	23.0	30.8	697.9	101.2		
41	80.5	20.4	27.4	624.2	90.5		
42	79.0	20.1	26.9	612.6	88.8		
43	92.5	23.6	31.6	717.3	104.0		

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Torque (lbf*ft)	BHP (kW)	BHP (hp)	BMEP (kPa)	BMEP (psi)	IMEP (kPa)	IMEP (psi)
BLD. VIIB							
44	91.8	23.5	31.6	712.1	103.3		
45	134.3	34.4	46.1	1041.7	151.1		
46	159.5	40.9	54.8	1236.8	179.4		
BLD. VIIC							
47	93.5	24.0	32.2	725.0	105.2		
48	154.3	39.5	53.0	1196.8	173.6		
49	129.5	33.1	44.4	1004.2	145.6		
50	95.0	24.3	32.6	736.7	106.8		
BLD. VIID							
51	88.3	22.6	30.3	684.3	99.2		
52	102.2	26.2	35.1	792.1	114.9		
53	103.6	26.5	35.5	803.1	116.5		
54	71.9	18.4	24.6	557.5	80.9		
55	69.0	17.7	23.7	535.2	77.6		
56	63.9	16.3	21.9	495.1	71.8		
57	78.5	17.9	23.9	608.6	88.3		
58	68.2	17.5	23.5	528.6	76.7		
59	72.4	18.5	24.8	561.4	81.4		
BLD.VIIIA							
60	88.2	22.6	30.3	684.2	99.2		
61	88.1	22.6	30.3	683.4	99.1		
62	82.4	21.2	28.4	638.7	92.6		
63	75.9	19.5	26.2	588.8	85.4		

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Torque (lbf*ft)	BHP (kW)	BHP (hp)	BMEP (kPa)	BMEP (psi)	IMEP (kPa)	IMEP (psi)
64	73.4	18.8	25.2	569.3	82.6		
65	68.1	17.4	23.3	527.7	76.5		
66	54.9	14.0	18.8	425.8	61.8		
67	108.9	27.8	37.3	844.1	122.4		
68							
BLD. VIIE							
71	107.4	27.5	36.8	832.9	120.8		
69	111.6	28.5	38.3	865.4	125.5		
70	111.9	28.6	38.4	867.8	125.9		
BLD. VIIF							
72							
BLD. VIIF							
73	109.4	28.0	37.5	848.5	123.1	1614.9	234.2
74	108.3	27.7	37.1	839.7	121.8	1592.4	230.9
75	105.2	26.9	36.1	815.6	118.3	1581.5	229.4
76	104.0	26.6	35.6	806.1	116.9	1629.5	236.3
77	103.1	26.4	35.3	799.3	115.9	1610.5	233.6

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Torque (lbf*ft)	BHP (kW)	BHP (hp)	BMEP (kPa)	BMEP (psi)	IMEP (kPa)	IMEP (psi)
BLD. IXA:							
78	111.3	28.5	38.2	863.3	125.2		
79	107.0	27.4	36.7	829.6	120.3		
80	96.4	24.6	33.0	747.1	108.4		
BLD. XA:							
81	119.1	30.4	40.8	923.4	133.9		
82	123.6	31.6	42.4	958.3	139.0		
83	128.2	32.8	43.9	994.0	144.2		
BLD. XIA:							
84	113.5	28.9	38.8	879.7	127.6		
85	103.7	26.5	35.6	804.3	116.6		

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel Flow (kg)	Fuel Flow (lbs)	Sample Time (min)	Fuel Flow (kg/hr)	Fuel Flow (lbs/hr)	BSFC (kg/kWh)	BSFC (lb/bhph)
BUILD I:							
1	0.170	0.375	2.430	4.204	9.259	0.260	0.427
2	0.170	0.375	2.429	4.205	9.263	0.261	0.429
3	0.227	0.500	2.364	5.761	12.690	0.246	0.405
4	0.318	0.700	2.547	7.486	16.490	0.244	0.400
5	0.284	0.625	2.117	8.042	17.714	0.260	0.428
6	0.284	0.625	2.120	8.032	17.691	0.269	0.442
7	0.284	0.625	2.111	8.066	17.766	0.252	0.415
8	0.284	0.625	1.882	9.047	19.928	0.262	0.430
9	0.284	0.625	1.765	9.644	21.242	0.268	0.440
10	0.284	0.625	2.101	8.102	17.847	0.287	0.471
BUILD IIA							
11	0.114	0.250	1.580	4.310	9.494	0.348	0.572
12	0.170	0.375	2.396	4.264	9.392	0.667	1.096
BUILD IIB							
13	0.284	0.625	2.985	5.704	12.564	0.340	0.559
14	0.341	0.750	2.740	7.455	16.421	0.330	0.542
15	0.341	0.750	2.774	7.365	16.222	0.320	0.526
16	0.341	0.750	2.748	7.434	16.376	0.331	0.544
17	0.341	0.750	2.725	7.498	16.516	0.329	0.541
18	0.341	0.750	2.612	7.823	17.230	0.343	0.563
19	0.341	0.750	2.591	7.885	17.368	0.366	0.602
BUILD IIC							
20	0.341	0.750	2.767	7.384	16.265	0.320	0.526
21	0.341	0.750	2.763	7.393	16.285	0.325	0.534
22	0.341	0.750	2.758	7.408	16.316	0.336	0.552
23	0.341	0.750	1.809	11.294	24.876	0.441	0.724
24	0.341	0.750	2.050	9.968	21.957	0.385	0.632
BUILD VIA							
25							

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel Flow (kg)	Fuel Flow (lbs)	Sample Time (min)	Fuel Flow (kg/hr)	Fuel Flow (lbs/hr)	BSFC (kg/kWh)	BSFC (lb/bhph)
BUILD VIB							
26	0.284	0.625	1.986	8.574	18.885	0.336	0.551
27	0.284	0.625	1.860	9.155	20.165	0.428	0.703
BUILD VIC							
28	0.284	0.625	2.111	8.066	17.767	0.272	0.447
29	0.284	0.625	2.099	8.111	17.866	0.280	0.460
BUILD VID					0.990458		
					0.984983		
30	0.284	0.625	2.131	7.989	17.597	0.276	0.453
31	0.284	0.625	2.124	8.016	17.655	0.335	0.550
BUILD VIE							
34	0.284	0.625	2.115	8.048	17.728	0.371	0.609
33	0.284	0.625	2.103	8.097	17.834	0.337	0.554
32	0.284	0.625	2.091	8.143	17.937	0.312	0.512
34	0.284	0.625	2.115	8.116	17.876	0.371	0.609
33	0.284	0.625	2.103	8.124	17.894	0.337	0.554
32	0.284	0.625	2.091	8.143	17.937	0.312	0.512
BLD. VIIA							
36	0.284	0.625	2.106	8.083	17.803	0.362	0.595
37	0.284	0.625	2.110	8.067	17.770	0.331	0.544
35	0.284	0.625	2.113	8.059	17.750	0.323	0.531
35	0.284	0.625	2.113	8.059	17.750	0.323	0.531
38	0.284	0.625	2.124	8.014	17.653	0.325	0.534
39	0.284	0.625	2.104	8.092	17.823	0.336	0.552
40	0.284	0.625	2.100	8.105	17.854	0.353	0.580
41	0.284	0.625	2.098	8.114	17.871	0.397	0.652
42	0.284	0.625	2.096	8.123	17.891	0.404	0.664
43	0.284	0.625	2.107	8.080	17.798	0.343	0.564

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel Flow (kg)	Fuel Flow (lbs)	Sample Time (min)	Fuel Flow (kg/hr)	Fuel Flow (lbs/hr)	BSFC (kg/kWh)	BSFC (lb/bhph)
BLD. VIIB							
44	0.284	0.625	2.029	8.392	18.485	0.356	0.585
45	0.284	0.625	1.294	13.157	28.980	0.383	0.629
46	0.284	0.625	1.088	15.648	34.467	0.383	0.629
BLD. VIIC							
47	0.284	0.625	2.045	8.325	18.337	0.347	0.570
48	0.284	0.625	1.086	15.672	34.520	0.397	0.652
49	0.284	0.625	1.445	11.779	25.946	0.355	0.584
50	0.284	0.625	1.949	8.735	19.241	0.360	0.591
BLD. VIID							
				CORRECTED	FOR WATER		
51	0.284	0.625	1.673	7.500	16.520	0.332	0.546
							0.957894
52	0.284	0.625	2.044	8.331	18.349	0.318	0.523
53	0.284	0.625	2.044	8.329	18.346	0.314	0.517
54	0.284	0.625	2.361	7.210	15.881	0.392	0.644
55	0.284	0.625	2.357	7.222	15.908	0.409	0.672
56	0.284	0.625	2.354	7.233	15.933	0.443	0.727
57	0.114	0.250	0.699	7.185	15.827	0.403	0.661
58	0.114	0.250	0.777	6.461	14.232	0.369	0.606
59	0.114	0.250	0.698	7.191	15.838	0.388	0.638
BLD.VIIIA							
60	0.284	0.625	2.011	8.465	18.644	0.375	0.616
61	0.284	0.625	2.011	8.466	18.647	0.375	0.616
62	0.284	0.625	2.006	8.486	18.691	0.401	0.659
63	0.284	0.625	2.004	8.496	18.713	0.436	0.715

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel Flow (kg)	Fuel Flow (lbs)	Sample Time (min)	Fuel Flow (kg/hr)	Fuel Flow (lbs/hr)	BSFC (kg/kWh)	BSFC (lb/bhph)
64	0.284	0.625	1.988	8.565	18.866	0.456	0.750
65	0.284	0.625	2.003	8.500	18.722	0.488	0.802
66	0.284	0.625	2.009	8.473	18.663	0.604	0.991
67	0.341	0.750	1.626	12.562	27.670	0.451	0.741
68							
BLD. VIIE							
71	0.341	0.750	2.050	9.968	21.957	0.363	0.596
							0.596
							0.576
							0.572
69	0.341	0.750	2.043	9.998	22.023	0.350	0.576
70	0.341	0.750	2.051	9.963	21.944	0.348	0.572
BLD. VIIF							
72							
BLD. VIIF							
73	0.341	0.750	2.054	9.945	21.905	0.355	0.584
74	0.341	0.750	2.054	9.945	21.905	0.359	0.590
75	0.341	0.750	2.060	9.919	21.848	0.369	0.606
76	0.341	0.750	2.056	9.937	21.887	0.374	0.614
77	0.341	0.750	2.050	9.964	21.948	0.378	0.621

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel Flow (kg)	Fuel Flow (lbs)	Sample Time (min)	Fuel Flow (kg/hr)	Fuel Flow (lbs/hr)	BSFC (kg/kWh)	BSFC (lb/bhph)
BLD. IXA:							
78	0.341	0.750	2.052	9.958	21.933	0.350	0.575
79	0.341	0.750	2.051	9.963	21.944	0.364	0.598
80	0.341	0.750	2.036	10.037	22.108	0.407	0.669
BLD. XA:							
81	0.341	0.750	2.058	9.927	21.866	0.326	0.536
82	0.341	0.750	2.061	9.914	21.838	0.314	0.515
83	0.341	0.750	2.052	9.958	21.933	0.304	0.499
BLD. XIA:							
84	0.341	0.750	2.056	9.935	21.884	0.344	0.564
85	0.341	0.750	2.056	9.938	21.891	0.375	0.616

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Orifice del p in/H2O	Mass airflow (lbs/hr)	Mass airflow (kg/hr)	Air/Fuel ratio (x:1)	Exhaust Flow (kg/hr)	Exhaust Flow (kg/min)	Orifice Meter (psig)
BUILD I:							
1	32.0	422.8	191.8	45.7	196.0	3.3	12.6
2	32.0	424.3	192.5	45.8	196.7	3.3	12.5
3	32.4	424.2	192.4	33.4	198.2	3.3	12.3
4	32.0	422.2	191.5	25.6	199.0	3.3	12.2
5	28.8	399.2	181.1	22.5	189.1	3.2	12.1
6	28.7	325.7	147.8	18.4	155.8	2.6	3.2
7	29.7	402.7	182.7	22.7	190.7	3.2	11.9
8	29.3	400.1	181.5	20.1	190.5	3.2	11.9
9	29.6	401.2	182.0	18.9	191.6	3.2	11.8
10	23.8	359.1	162.9	20.1	171.0	2.8	11.7
BUILD IIA							
11	23.5	326.3	148.0	34.4	152.3	2.5	7.5
12	29.4	402.9	182.8	42.9	187.0	3.1	12.2
BUILD IIB							
13	24.2	364.8	165.5	29.0	171.2	2.9	11.9
14	22.1	348.3	158.0	21.2	165.4	2.8	12.0
15	26.0	394.4	178.9	24.3	186.3	3.1	14.4
16	25.2	383.4	173.9	23.4	181.3	3.0	14.0
17	26.4	407.4	184.8	24.7	192.3	3.2	16.1
18	22.7	347.7	157.7	20.2	165.5	2.8	11.7
19	18.7	290.1	131.6	16.7	139.5	2.3	7.8
BUILD IIC							
20	32.1	401.6	182.2	24.69	189.5	3.2	10.2
21	27.9	397.6	180.3	24.41	187.7	3.1	13.4
22	26.6	397.4	180.3	24.36	187.7	3.1	14.7
23	21.3	330.5	149.9	13.29	161.2	2.7	10.8
24	22.1	337.8	153.2	15.38	163.2	2.7	10.8
BUILD VIA							
25							

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Orifice del p in/H2O	Mass airflow (lbs/hr)	Mass airflow (kg/hr)	Air/Fuel ratio (x:1)	Exhaust Flow (kg/hr)	Exhaust Flow (kg/min)	Orifice Meter (psig)
BUILD VIB							
26	23.2	358.0	162.4	18.96	171.0	2.8	11.8
27	18.0	314.4	142.6	15.59	151.8	2.5	11.7
BUILD VIC							
28	32.0	383.9	174.1	21.61	182.2	3.0	8.7
29	29.7	391.0	177.3	21.88	185.5	3.1	11.5
BUILD VID	1.015074			1.027680			
	0.985479			1.009056			
30	27.8	394.5	179.0	22.42	186.9	3.1	13.1
31	21.7	343.0	155.6	19.43	163.6	2.7	12.7
BUILD VIE							
34	19.8	288.6	130.9	16.28	139.0	2.3	6.4
33	21.5	316.3	143.5	17.74	151.6	2.5	8.6
32	25.2	364.8	165.5	20.34	173.6	2.9	11.6
34	19.8	291.0	132.0	16.28	140.1	2.3	6.4
33	21.5	317.4	144.0	17.74	152.1	2.5	8.6
32	25.2	364.8	165.5	20.34	173.6	2.9	11.6
BLD. VIIA							
36	30.5	399.4	181.2	22.44	189.3	3.2	11.1
37	30.5	398.1	180.6	22.40	188.6	3.1	11.0
35	31.1	404.3	183.4	22.78	191.4	3.2	11.1
35	31.1	404.3	183.4	22.78	191.4	3.2	11.1
38	28.7	404.1	183.3	22.89	191.3	3.2	13.5
39	26.7	396.4	179.8	22.24	187.9	3.1	14.6
40	19.8	295.0	133.8	16.53	141.9	2.4	7.2
41	19.3	292.4	132.6	16.36	140.7	2.3	7.3
42	18.2	272.9	123.8	15.25	131.9	2.2	5.7
43	26.2	394.0	178.7	22.14	186.8	3.1	14.5

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Orifice del p in/H2O	Mass airflow (lbs/hr)	Mass airflow (kg/hr)	Air/Fuel ratio (x:1)	Exhaust Flow (kg/hr)	Exhaust Flow (kg/min)	Orifice Meter (psig)
BLD. VIIB							
44	26.8	396.3	179.8	21.44	188.1	3.1	14.7
45	30.1	456.2	206.9	15.74	220.1	3.7	20.2
46	38.2	553.8	251.2	16.07	266.8	4.4	26.1
BLD. VIIC							
47	25.9	387.7	175.9	21.14	184.2	3.1	14.6
48	36.6	553.6	251.1	16.04	266.8	4.4	28.1
49	38.7	568.5	257.9	21.91	269.7	4.5	28.1
50	41.2	592.9	268.9	30.81	277.7	4.6	29.1
BLD. VIID							
51	28.0	408.4	185.2	24.72	192.7	3.2	15.5
52	26.8	397.0	180.1	21.64	188.4	3.1	14.8
53	26.6	395.0	179.2	21.53	187.5	3.1	14.7
54	16.2	242.3	109.9	15.25	117.1	2.0	3.7
55	16.5	244.1	110.7	15.34	117.9	2.0	3.6
56	16.4	242.1	109.8	15.20	117.1	2.0	3.5
57	13.9	224.2	101.7	14.16	108.9	1.8	3.8
58	17.6	252.6	114.6	17.75	121.0	2.0	3.8
59	17.0	248.2	112.6	15.67	119.8	2.0	3.8
BLD.VIIIA							
60	18.3	389.9	176.9	20.91	185.3	3.1	27.8
61	18.1	388.7	176.3	20.85	184.8	3.1	27.6
62	15.8	334.8	151.9	17.91	160.3	2.7	21.4
63	14.0	297.6	135.0	15.91	143.5	2.4	17.6

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Orifice del p in/H2O	Mass airflow (lbs/hr)	Mass airflow (kg/hr)	Air/Fuel ratio (x:1)	Exhaust Flow (kg/hr)	Exhaust Flow (kg/min)	Orifice Meter (psig)
64	14.0	298.4	135.3	15.81	143.9	2.4	17.7
65	14.0	298.4	135.3	15.94	143.8	2.4	17.7
66	14.2	300.4	136.2	16.09	144.7	2.4	17.7
67	19.2	441.6	200.3	15.96	212.9	3.5	37.2
68							
BLD. VIIE							
71	25.5	386.4	175.3	17.60	185.2	3.1	14.8
	0.026	0.00					
	0.028	3.36					
	0.03	4.03					
69	25.3	385.6	174.9	17.51	184.9	3.1	14.8
70	25.4	387.3	175.7	17.65	185.7	3.1	15.0
BLD. VIIF							
72							
BLD. VIIF							
73	25.2	384.3	174.3	17.54	184.3	3.1	14.9
74	24.1	384.3	174.3	17.54	184.3	3.1	16.4
75	23.5	384.1	174.2	17.58	184.2	3.1	17.3
76	22.2	382.8	173.6	17.49	183.6	3.1	19.2
77	20.9	381.2	172.9	17.37	182.9	3.0	20.6

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Orifice del p in/H2O	Mass airflow (lbs/hr)	Mass airflow (kg/hr)	Air/Fuel ratio (x:1)	Exhaust Flow (kg/hr)	Exhaust Flow (kg/min)	Orifice Meter (psig)
BLD. IXA:							
78	27.3	395.7	179.5	18.04	189.4	3.2	14.8
79	25.7	371.8	168.7	16.94	178.6	3.0	13.0
	GUESS						
80	24.1	342.5	155.4	15.49	165.4	2.8	10.4
BLD. XA:							
81	26.9	396.2	179.7	18.12	189.7	3.2	14.6
82	29.2	425.1	192.8	19.47	202.7	3.4	16.4
83	31.9	465.5	211.2	21.23	221.1	3.7	19.4
BLD. XIA:							
84	25.1	380.7	172.7	17.40	182.6	3.0	14.2
85	21.9	332.6	150.9	15.19	160.8	2.7	10.7

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	MEAS'D TEMP RISE (F)	Smoke (Bosch)	Cyl-Pres File Name	PK. PR. (PSI)	PK. PR. TMG ATDC (ca)	Vol Eff	Brake Ther.Eff
BLD. IXA:							
78	1271	2.2	ST0828AA	1210	1	88.2	23.9
79	1339	2.9	ST0828AB	1119	1	88.4	23.0
80	1421	5.8	ST0828AC	1044	2	89.7	20.6
BLD. XA:							
81	1270	0.6	ST0904AA	1124	0	89.2	25.7
82	1217	0.3	ST0904AB	1161	-0	90.4	26.7
83	1130	0.1	ST0904AC	1298	0	89.9	27.6
BLD. XIA:							
84	1205	2.0	ST0917AA	1056	9	87.0	24.4
85	1329	3.7	ST0917AB	905	8	86.0	22.3

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	MEAS'D TEMP RISE (F)	Smoke (Bosch)	Cyl-Pres File Name	PK. PR. (PSI)	PK. PR. TMG ATDC (ca)	Vol Eff	Brake Ther.Eff
64	1343	4.6	ST0719AA	997	10	59.6	18.4
65	1373	3.1	ST0719AB	826	?	59.7	17.1
66	1435	3.1	ST0719AC	805	5	60.4	13.9
67	1508	2.7	ST0719AD	1539	9	78.1	18.6
68							
BLD. VIIE							
71	1248	2.1	ST0820AB	1106	1	86.4	23.1
69	1231	2.0	ST0819AA	1056	-4	86.2	23.9
70	1194	1.8	ST0820AA	1075	-4	86.2	24.1
BLD. VIIF							
72							
BLD. VIIF							
73	1199	1.8	ST0823AA	1055	-4	84.9	23.6
74	1167	1.7	ST0823AB	1072	-5	87.3	23.3
75	1113	1.7	ST0823AC	1131	-4	89.5	22.7
76	1116	1.9	ST0823AD	1167	-4	90.5	22.4
77	1091	1.7	ST0826AA	1211	-3	91.6	22.2

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	MEAS'D TEMP RISE (F)	Smoke (Bosch)	Cyl-Pres File Name	PK. PR. (PSI)	PK. PR. TMG ATDC (ca)	Vol Eff	Brake Ther.Eff
BLD. VIIB							
44	1000	2.1	ST0612AA	987		89.4	23.5
45	1424	2.9	ST0612AB	1183		86.5	21.9
46	1397	2.5	ST0612AC	1378		88.6	21.9
BLD. VIIC							
47	1014	2.5	ST0619AA	987		88.0	24.1
48	1483	2.3	ST0619AB	1495	2	85.2	21.1
49	1111	1.9	ST0619AC	1495	4	87.7	23.6
50	785	2.8	ST0619AD	1502	3	89.7	23.3
LD. VIID							
51	819	<.1	ST0625AA	1074	2	89.0	25.2
52	1052	0.7	ST0626AA	1052	13	88.2	26.3
53	1037	0.7	ST0627AA	996	10	88.7	26.6
54	1244	5.4	ST0627AB	778	4	86.0	21.4
55	1286	5.0	ST0627AC	651	13	87.6	20.5
56	1300	2.3	ST0627AD	543	31	87.0	18.9
57	1065	5.6	ST0627AE	796	?	87.1	20.8
58	937	1.1	ST0627AF	860	6	87.2	22.7
59	1071	3.2	ST0627AG	864	?	86.1	21.6
VIIIA							
60	1052	1.2	ST0717AA	1249	6	59.9	22.3
61	1079	1.2	ST0718AA	1304	12	59.2	22.3
62	1195	2.3	ST0718AB	1164	8	58.6	20.9
63	1321	4.6	ST0718AC	1138	7	58.9	19.2

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	MEAS'D TEMP RISE (F)	Smoke (Bosch)	Cyl-Pres File Name	PK. PR. (PSI)	PK. PR. TMG ATDC (ca)	Vol Eff	Brake Ther.Eff
BUILD VIB							
26	1427	0.5	ST0509AA,	1074		75.3	25.0
27		7.8	ST0509AC	1081		68.0	19.6
BUILD VIC							
28	1138	0.3	ST0516AA	1023		85.5	30.8
29	1101	0.2	ST0516AB	1103		91.6	29.9
BUILD VID							
30	1039	0.1	ST0517AA	1096		94.1	30.3
31	1272	0.4	ST0517AB	1045		81.8	25.0
BUILD VIE							
34	1265	6.7	ST0528AC	1175		87.5	22.6
33	1178	3.9	ST0528AB	972		87.5	24.8
32	1074	1.2	ST0528AA	921		89.5	26.9
34	1265	6.7	ST0528AC	1175		87.5	22.6
33	1178	3.9	ST0528AB	972		87.5	24.8
32	1074	1.2	ST0528AA	921		89.5	26.9
BLD. VIIA							
36	1076	0.5	ST0604AB	856		80.5	23.1
37	1041	1.7	ST0604AC	820		80.5	25.3
35	1034	3.5	ST0604AA	856		81.4	25.9
35	1034	3.5	ST0604AA	856		81.4	25.9
38	965	3.0	ST0604AD	958		85.6	25.8
39	964	3.0	ST0604AE	994		88.0	24.9
40	1195	2.5	ST0604AF	718		85.1	23.7
41	1214	0.8	ST0604AG	740		85.9	21.1
42	1263	1.9	ST0604AH	682		85.5	20.7
43	953	2.1	ST0605AA	1001		88.0	24.4

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	MEAS'D TEMP RISE (F)	Smoke (Bosch)	Cyl-Pres File Name	PK. PR. (PSI)	PK. PR. TMG ATDC (ca)	Vol Eff	Brake Ther.Eff
BUILD I:							
1	NA	NA	ST0123AA			100.3	32.2
2	NA	NA	ST0124AA			98.7	32.1
3	NA	NA	*AC;*AD			99.3	34.0
4	NA	NA	*AE;*AF			100.4	34.4
5	NA	NA	ST0130AA			97.3	32.2
6	NA	0.7	ST0204AA			82.1	31.1
7	NA	0.2	ST0204AB			99.1	33.2
8	NA	0.2	ST0204AC			98.2	32.0
9	NA	0.2	ST0204AD			98.3	31.3
10	NA	0.2	ST0205AA			88.0	29.2
BUILD IIA							
11	NA	-	ST0219AA			93.4	24.1
12	NA	-	ST0220AA			99.5	12.6
BUILD IIB							
13	807	6.4	ST0308AA			90.3	24.6
14	1237	7.6	ST0308AB			85.7	25.4
15	948	6.6	ST0308AC			88.1	26.2
16	931	7.0	ST0312AA	1836		88.1	25.3
17	889	7.0	ST0312AB	1981		87.6	25.4
18	1125	7.2	ST0312AC	1734		85.6	24.4
19	1338	7.6	ST0312AD	1502		81.5	22.9
BUILD IIC							
20	979	7.3	ST0329AA	1676		81.9	26.1
21	938	7.2	ST0329AB	1836		87.4	25.8
22	934	6.9	ST0329AC	1828		89.4	24.9
23	1304	8.5	ST0329AD	2010		85.0	19.0
24	1424	8.4	ST0329AD	1705		86.7	21.8
BUILD VIA							
25	1000	0.9	ST0502AA				

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Orifice (F)	Exhaust Temp (C)	Exhaust Temp (F)	Oil Temp (C)	Oil Temp (F)	Precham Upper (C)	Precham Upper (F)
BLD. IXA:							
78	102	830	1526	96	204	-	-
79	102	867	1593	95	203	-	-
	GUESS		GUESS		GUESS		
80	102	913	1675	95	203	-	-
BLD. XA:							
81	88	829	1524	97	206	-	-
82	89	800	1472	97	207	-	-
83	89	751	1384	95	203	-	-
BLD. XIA:							
84	87	793	1460	97	206	-	-
85	87	862	1584	96	205	-	-

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Orifice (F)	Exhaust Temp (C)	Exhaust Temp (F)	Oil Temp (C)	Oil Temp (F)	Precham Upper (C)	Precham Upper (F)
64	98	870	1599	98	208	-	-
65	98	888	1630	96	205	-	-
66	96	923	1693	96	205	-	-
67	101	970	1778	102	215	-	-
68							
BLD. VIIE							
71	90	817	1503	96	205	-	-
69	87	806	1483	96	204	-	-
70	87	786	1448	96	204	-	-
BLD. VIIF							
72							
BLD. VIIF							
73	93	788	1450	98	209	-	-
74	96	801	1475	101	214	-	-
75	98	798	1468	104	219	-	-
76	102	834	1533	106	223	-	-
77	95	849	1560	106	222	-	-

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Orifice (F)	Exhaust Temp (C)	Exhaust Temp (F)	Oil Temp (C)	Oil Temp (F)	Precham Upper (C)	Precham Upper (F)
BLD. VIIB							
44	89	681	1259	98	208	-	-
45	94	919	1686	96	205	-	-
46	98	899	1650	99	211	-	-
BLD. VIIC							
47	93	691	1276	97	206	-	-
48	102	952	1745	101	214	-	-
49	103	744	1372	102	215	-	-
50	104	563	1046	99	211	-	-
BLD. VIID							
51	95	578	1072	96	205	-	-
52	89	709	1308	98	209	-	-
53	90	701	1294	100	212	-	-
54	92	816	1500	98	209	-	-
55	92	840	1544	97	207	-	-
56	93	848	1559	97	206	-	-
57	98	714	1318	95	203	-	-
58	96	644	1192	97	207	-	-
59	96	719	1326	98	208	-	-
BLD.VIIIA							
60	102	712	1313	96	204	-	-
61	96	723	1333	97	206	-	-
62	98	786	1447	97	206	-	-
63	99	855	1571	96	204	-	-

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Orifice (F)	Exhaust Temp (C)	Exhaust Temp (F)	Oil Temp (C)	Oil Temp (F)	Precham Upper (C)	Precham Upper (F)
BUILD VIB							
26	78	869	1597	92	198	-18	1550 EST
27	79	-18	"1800 +"	91	195	912	1674
BUILD VIC							
28	93	679	1255	96	204	801	1474
29	94	701	1295	96	204	870	1598
BUILD VID							
30	90	704	1300	98	209	893	1640
31	98	831	1528	97	206	931	1708
BUILD VIE							
34	96	819	1507	97	206	110	230
33	96	774	1426	98	208	110	230
32	93	718	1325	94	202	110	230
34	96	819	1507	97	206	110	230
33	96	774	1426	98	208	110	230
32	93	718	1325	94	202	110	230
BLD. VIIA							
36	86	639	1183	98	208	-	-
37	87	620	1148	96	204	-	-
35	84	617	1142	96	204	-	-
35	84	617	1142	96	204	-	-
38	88	624	1156	96	205	-	-
39	90	658	1216	96	205	-	-
40	91	778	1433	99	210	-	-
41	90	794	1461	99	210	-	-
42	92	819	1507	96	204	-	-
43	87	652	1206	96	204	-	-

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Orifice (F)	Exhaust Temp (C)	Exhaust Temp (F)	Oil Temp (C)	Oil Temp (F)	Precham Upper (C)	Precham Upper (F)
BUILD I:							
1	79	324	615	77	170	NA	NA
2	76	320	608	73	163	NA	NA
3	78	422	792	81	178	NA	NA
4	74	334	633	75	167	NA	NA
5	74	599	1111	91	195	NA	NA
6	75	681	1257	99	210	NA	NA
7	78	599	1110	101	213	NA	NA
8	78	674	1245	102	215	NA	NA
9	79	719	1326	101	213	NA	NA
10	78	705	1301	101	213	NA	NA
BUILD IIA							
11	76	353	668	96	204	NA	NA
12	75	445	833	101	213	NA	NA
BUILD IIB							
13	70	571	1059	94	202	NA	NA
14	74	810	1490	93	199	NA	NA
15	75	646	1194	97	206	NA	NA
16	78	642	1187	100	212	NA	NA
17	76	620	1149	101	213	NA	NA
18	80	746	1374	98	208	NA	NA
19	83	861	1582	97	207	NA	NA
BUILD IIC							
20	79	573	1064	103	217	NA	NA
21	81	619	1147	101	214	NA	NA
22	81	643	1190	101	214	NA	NA
23	82	847	1557	101	213	NA	NA
24	79	913	1676	99	211	NA	NA
BUILD VIA							
25	80	649	1200	91	195	816	1500

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel pres (kPa)	Baro\Pres (kPa)	Baro\Pres (psi)	Humidity (%)	Int Surge Tank T (C)	Int Surge Tank T (F)	Intake Orifice (C)
BLD. IXA:							
78	NA	48.274	14.295	39	124	255	39
79	NA	48.274	14.295	39	123	254	39
80	NA	48.274	14.295	39	123	GUESS 254	39
BLD. XA:							
81	NA	48.207	14.276	82	123	254	31
82	NA	48.207	14.276	82	124	256	32
83	NA	48.207	14.276	82	123	254	32
BLD. XIA:							
84	NA	48.274	14.295	40	124	255	30
85	NA	48.274	14.295	40	124	256	31

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel pres (kPa)	Baro\Pres (kPa)	Baro\Pres (psi)	Humidity (%)	Int Surge Tank T (C)	Int Surge Tank T (F)	Intake Orifice (C)
64	NA	48.307	14.305	33	124	256	36
65	NA	48.307	14.305	33	125	257	36
66	NA	48.307	14.305	33	126	258	36
67	NA	48.307	14.305	33	132	270	38
68							
BLD. VIIE							
71	NA	48.108	14.246	44	124	255	32
69	NA	47.942	14.197	61	122	252	30
70	NA	48.124	14.251	53	123	254	30
BLD. VIIF							
72							
BLD. VIIF							
73	NA	48.406	14.335	53	121	251	34
74	NA	48.406	14.335	53	153	308	35
75	NA	48.406	14.335	53	179	355	37
76	NA	48.241	14.286	35	214	417	39
77	NA	48.241	14.286 ?	35	243	469	35

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel pres (kPa)	Baro\Pres (kPa)	Baro\Pres (psi)	Humidity (%)	Int Surge Tank T (C)	Int Surge Tank T (F)	Intake Orifice (C)
BLD. VIIB							
44	NA	48.440	14.345	64	126	259	32
45	NA	48.440	14.345	64	128	262	34
46	NA	48.440	14.345	64	123	253	37
BLD. VIIC							
47	NA	48.473	14.354	46	128	262	34
48	NA	48.473	14.354	46	128	262	39
49	NA	48.473	14.354	46	127	261	39
50	NA	48.473	14.354	46	127	261	40
BLD. VIID							
51	NA	48.440	14.345	61	123	253	35
52	NA	48.572	14.384	61	124	256	31
53	NA	48.605	14.394	62	125	257	32
54	NA	48.605	14.394	62	124	256	33
55	NA	48.605	14.394	62	126	258	33
56	NA	48.605	14.394	62	126	259	34
57	NA	48.605	14.394	62	123	253	36
58	NA	48.605	14.394	62	124	256	36
59	NA	48.605	14.394	62	124	256	36
BLD.VIIIA							
60	NA	48.324	14.310	34	128	262	39
61	NA	48.307	14.305	39	123	254	36
62	NA	48.307	14.305	39	122	252	36
63	NA	48.307	14.305	39	121	250	37

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel pres (kPa)	Baro\Pres (kPa)	Baro\Pres (psi)	Humidity (%)	Int Surge Tank T (C)	Int Surge Tank T (F)	Intake Orifice (C)
BUILD VIB							
26	NA	50.754	15.030	-	77	170	26
27	NA	50.754	15.030	-	76	169	26
BUILD VIC							
28	NA	48.266	14.293	-	47	117	34
29	NA	48.266	14.293	-	90	194	34
BUILD VID							
30	NA	49.643	14.701	-	127	261	32
31	NA	49.560	14.676	-	124	256	37
BUILD VIE							
34	NA	49.858	14.765	-	117	242	36
33	NA	49.858	14.765	-	120	248	36
32	NA	49.858	14.765	-	122	251	34
34	NA	49.858	14.765	-	117	242	36
33	NA	49.858	14.765	-	120	248	36
32	NA	49.858	14.765	-	122	251	34
BLD. VIIA							
36	NA	49.593	14.686	47	42	107	30
37	NA	49.593	14.686	47	42	107	30
35	NA	49.593	14.686	47	42	108	29
35	NA	49.593	14.686	47	42	108	29
38	NA	49.543	14.671	36	88	191	31
39	NA	49.543	14.671	36	122	252	32
40	NA	49.543	14.671	36	114	238	33
41	NA	49.543	14.671	36	119	247	32
42	NA	49.543	14.671	36	118	244	33
43	NA	49.925	14.784	27	123	253	30

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Fuel pres (kPa)	Baro\Pres (kPa)	Baro\Pres (psi)	Humidity (%)	Int Surge Tank T (C)	Int Surge Tank T (F)	Intake Orifice (C)
BUILD I:							
1	NA	49.012	14.514	18	112	233	26
2	NA	49.643	14.701	18	111	232	24
3	NA	49.643	14.701	22	109	229	26
4	NA	49.643	14.701	22	113	236	23
5	NA	49.145	14.554	28	123	253	23
6	NA	49.510	14.662	36	27	81	24
7	NA	49.510	14.662	36	123	253	25
8	NA	49.510	14.662	36	123	253	25
9	NA	49.510	14.662	36	123	254	26
10	NA	49.394	14.627	36	122	252	26
BUILD IIA							
11	NA	48.714	14.426	-	26	78	24
12	NA	48.930	14.490	-	128	262	24
BUILD IIB							
13	NA	48.880	14.475	-	122	252	21
14	NA	48.880	14.475	-	123	254	23
15	NA	48.880	14.475	-	119	246	24
16	NA	48.349	14.318	-	124	256	25
17	NA	48.349	14.318	-	126	259	24
18	NA	48.349	14.318	-	121	249	27
19	NA	48.349	14.318	-	118	244	28
BUILD IIC							
20	NA	48.283	14.298	-	29	84	26
21	NA	48.283	14.298	-	98	209	27
22	NA	48.283	14.298	-	124	256	27
23	NA	48.283	14.298	-	123	253	28
24	NA	48.283	14.298	-	122	252	26
BUILD VIA							
25	NA			-	93	200	27

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Surge Tk (psi)	Exhaust pres (kPa)	Exhaust pres in/Hg	Blowby pres (kPa)	Blowby pres in/H2O	Oil (kPa)	Oil (psig)
BLD. IXA:							
78	28.3	7.0	28.0	0.5	2.0	NA	NA
79	26.5	6.0	24.0	0.5	2.0	NA	NA
80	24.0	5.4	21.5	0.5	1.9	NA	NA
BLD. XA:							
81	28.0	6.9	27.8	0.9	3.8	NA	NA
82	29.7	7.6	30.5	1.0	4.0	NA	NA
83	32.6	9.1	36.5	1.1	4.3	NA	NA
BLD. XIA:							
84	27.7	6.8	27.5	0.7	2.9	NA	NA
85	24.4	5.0	20.0	0.6	2.5	NA	NA

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Surge Tk (psi)	Exhaust pres (kPa)	Exhaust pres in/Hg	Blowby pres (kPa)	Blowby pres in/H2O	Oil (kPa)	Oil (psig)
64	31.6	8.6	34.5	0.3	1.4	NA	NA
65	31.6	8.6	34.5	0.3	1.2	NA	NA
66	31.5	8.5	34.0	0.3	1.1	NA	NA
67	36.4	18.4	74.0	0.9	3.5	NA	NA
68							
BLD. VIIE							
71	28.2	7.5	30.0	0.8	3.2	NA	NA
69	28.1	7.2	29.0	0.5	2.0	NA	NA
70	28.3	7.5	30.0	0.8	3.2	NA	NA
BLD. VIIF							
72							
BLD. VIIF							
73	28.4	7.5	30.3	0.8	3.1	NA	NA
74	29.8	8.0	32.0	0.8	3.1	NA	NA
75	30.8	8.0	32.0	0.8	3.2	NA	NA
76	32.7	9.3	37.5	0.9	3.8	NA	NA
77	34.1	10.0	40.3	0.9	3.8	NA	NA

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Surge Tk (psi)	Exhaust pres (kPa)	Exhaust pres in/Hg	Blowby pres (kPa)	Blowby pres in/H2O	Oil (kPa)	Oil (psig)
BLD. VIIB							
44	28.0	7.3	29.5	0.6	2.5	NA	NA
45	33.5	9.8	39.3	0.7	3.0	NA	NA
46	39.2	7.5	30.0	1.0	4.0	NA	NA
BLD. VIIC							
47	28.0	7.6	30.5	0.6	2.5	NA	NA
48	41.4	13.6	54.5	1.1	4.3	NA	NA
49	41.2	13.1	52.5	1.0	4.2	NA	NA
50	42.1	14.1	56.5	1.0	4.1	NA	NA
BLD. VIID							
51	28.8	7.7	31.0	0.6	2.5	NA	NA
52	28.4	7.5	30.0	0.9	3.8	NA	NA
53	28.1	7.2	29.0	0.6	2.5	NA	NA
54	17.8	2.0	8.0	0.3	1.4	NA	NA
55	17.6	2.0	8.0	0.3	1.4	NA	NA
56	17.6	2.0	8.0	0.3	1.4	NA	NA
57	18.2	1.8	7.1	0.3	1.2	NA	NA
58	18.2	1.8	7.1	0.3	1.2	NA	NA
59	18.2	1.8	7.1	0.3	1.2	NA	NA
BLD.VIIIA							
60	41.4	13.0	52.3	0.9	3.6	NA	NA
61	41.3	13.5	54.3	0.7	3.0	NA	NA
62	35.7	10.8	43.5	0.5	1.9	NA	NA
63	31.5	8.5	34.0	0.5	2.0	NA	NA

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Surge Tk (psi)	Exhaust pres (kPa)	Exhaust pres in/Hg	Blowby pres (kPa)	Blowby pres in/H2O	Oil (kPa)	Oil (psig)
BUILD VIB							
26	26.4	5.5	22.0	0.4	1.8	NA	NA
27	25.7	5.5	22.0	0.5	2.0	NA	NA
BUILD VIC							
28	23.0	0.7	3.0	0.4	1.8	NA	NA
29	24.8	0.7	3.0	0.4	1.8	NA	NA
BUILD VID							
30	26.9	0.7	2.9	0.5	2.0	NA	NA
31	26.7	5.9	23.8	0.7	2.8	NA	NA
BUILD VIE							
34	20.6	2.9	11.8	0.4	1.5	NA	NA
33	22.6	4.1	16.5	0.4	1.8	NA	NA
32	25.5	5.3	21.3	0.5	2.0	NA	NA
34	20.6	2.9	11.8	0.4	1.5	NA	NA
33	22.6	4.1	16.5	0.4	1.8	NA	NA
32	25.5	5.3	21.3	0.5	2.0	NA	NA
BLD. VIIA							
36	24.9	5.4	21.8	0.6	2.3	NA	NA
37	24.8	5.3	21.3	0.5	2.0	NA	NA
35	24.9	5.4	21.5	0.6	2.4	NA	NA
35	24.9	5.4	21.5	0.6	2.4	NA	NA
38	27.2	6.5	26.3	0.6	2.4	NA	NA
39	28.4	7.3	29.3	0.6	2.5	NA	NA
40	21.4	3.6	14.5	0.4	1.5	NA	NA
41	21.4	3.6	14.6	0.4	1.5	NA	NA
42	19.9	2.4	9.8	0.4	1.5	NA	NA
43	28.3	7.2	29.0	0.6	2.5	NA	NA

ENGINE TEST DATA FOR STOICHIOMETRIC DIESEL PROGRAM

Point	Intake Surge Tk (psi)	Exhaust pres (kPa)	Exhaust pres in/Hg	Blowby pres (kPa)	Blowby pres in/H2O	Oil (kPa)	Oil (psig)
BUILD I:							
1	26.1	0.0	0.0	0.1	0.3		NA
2	26.2	0.0	0.0	0.1	0.3		NA
3	26.1	0.0	0.0	0.1	0.4		NA
4	26.0	0.0	0.0	0.1	0.4		NA
5	25.9	0.0	0.0	0.1	0.4		NA
6	18.8	0.6	2.5	0.1	0.3		NA
7	25.6	0.7	3.0	0.1	0.3		NA
8	25.6	0.8	3.4	0.1	0.3		NA
9	25.6	0.9	3.5	0.1	0.3		NA
10	25.5	5.6	22.5	0.1	0.4		NA
BUILD IIA							
11	21.2	0.4	1.6	0.0	0.0	NA	NA
12	25.8	0.5	2.0	0.0	0.2	NA	NA
BUILD IIB							
13	25.5	5.8	23.5	0.1	0.6	NA	NA
14	25.5	5.7	23.0	0.1	0.6	NA	NA
15	27.9	6.5	26.3	0.1	0.6	NA	NA
16	27.5	6.4	25.9	0.4	1.5	NA	NA
17	29.5	7.8	31.3	0.3	1.3	NA	NA
18	25.3	5.1	20.3	0.3	1.1	NA	NA
19	22.1	3.5	14.3	0.2	0.7	NA	NA
BUILD IIC							
20	23.5	4.6	18.5	0.3	1.1	NA	NA
21	26.8	6.3	25.4	0.4	1.5	NA	NA
22	28.0	6.9	27.8	0.4	1.6	NA	NA
23	24.4	4.4	17.5	0.3	1.1	NA	NA
24	24.4	3.5	14.3	0.2	1.0	NA	NA
BUILD VIA							
25	21.7					NA	NA

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